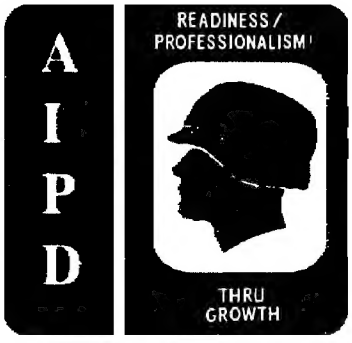
SUBCOURSE
MM0308

EDITION
9

INTRODUCTION TO ELECTRICITY
(REVISION DATE: 31 DECEMBER 1988)

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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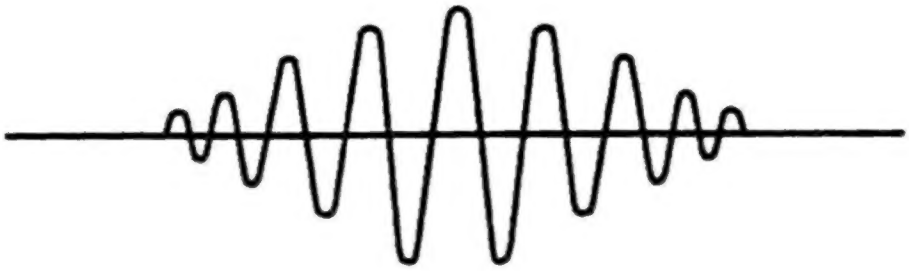


SUBCOURSE 308, INTRODUCTION TO ELECTRICITY

INTRODUCTION

Ben Franklin's experiment with a kite opened up a whole new way of life to later generations. As a result of this experiment, we have a world that has become dependent upon electricity. Almost all major industries lean heavily upon electricity to run their factories; radio, telephone and telegraph communications operate with electricity; medicine depends upon electricity for X-ray and diathermy equipment, various pumps, cooling and heating devices; homeowners use electricity to both heat and cool their homes, preserve food, run dishwashers and irons, and various entertainment devices; our homes and highways use electricity for lighting; ships, planes, trains, buses, and cars all require electricity to operate.

Of course, all these things that are so much a part of our lives must be maintained and repaired.

This subcourse is designed to teach you electrical fundamentals, which is the basis for repairing any electronic equipment.

This subcourse consists of one lesson, the lesson exercises and the subcourse examination.

Credit Hours: 6

PLEASE NOTE

Proponency for this subcourse has changed
from Signal (SS) to Missile & Munitions (MM).

REVIEWED AND REPRINTED WITH MINOR REVISIONS AUGUST 1976

LESSON

INTRODUCTION TO ELECTRICITY

SCOPE.....Explanation of electron theory; current flow and magnetic fields; Ohm's law; electrical power; magnetism; generation of ac; effects of resistance; capacitance and inductance on ac; impedance; characteristics of tuned circuits; resonance; modulation of RF; use of frequency in communications.

CREDIT HOURS.....4

TEXT ASSIGNMENT.....Attached Memorandum. para 1 thru 20

MATERIALS REQUIRED.....None

SUGGESTIONS.....None

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Know that current flow through a conductor always produces a magnetic field.

2. Understand how Ohm's law expresses the relationship of voltage, current, and resistance.

3. Know that the reactance of inductors and capacitors changes as frequency changes, but resistance remains stable.

4. Know that impedance is the total opposition to current flow in an ac circuit.

5. Know the effects of series- and parallel-tuned circuits when not resonant and at resonance.

ATTACHED MEMORANDUM

(This publication is provided for resident and nonresident instruction conducted by the US Army Signal Center and School. It reflects the current thought of this school and conforms to published Department of the Army doctrine as closely as possible.)

1. ELECTRON THEORY

a. General. Electricity is so much a part of our everyday life that we seldom consider why or how it performs such a variety of tasks for us at the

mere touch of a switch. What is the nature of this unseen phenomenon? This question cannot be answered, because the exact nature of electricity is not known. However, the uses, effects, and laws governing electrical action are well understood, and so these known characteristics will be described here.

b. The Nature of Matter. To study electricity, you must understand something about the constitution of matter. The smallest particle of matter that still retains the identity of the material being studied is the molecule. Every molecule is made up of atoms, which are the smallest amount of an element capable of entering into a chemical combination. The atom can be further subdivided into particles classified as protons, electrons, and neutrons. Protons are positively charged particles which, together with neutrons, are found in the nucleus of the atom. The neutrons have no electrical charge. The negatively charged electrons move in orbits around the nucleus. It is the study of the action of these negatively charged particles that concerns you in the study of electricity and electronics.

(1) Figure 1 shows the diagram of the helium atom and its parts. Since all elements are made up of a different number of electrons, protons, and neutrons, we may assume that the difference between the various elements is in the number of electrons, protons, and neutrons each element has, and in how these parts are arranged.

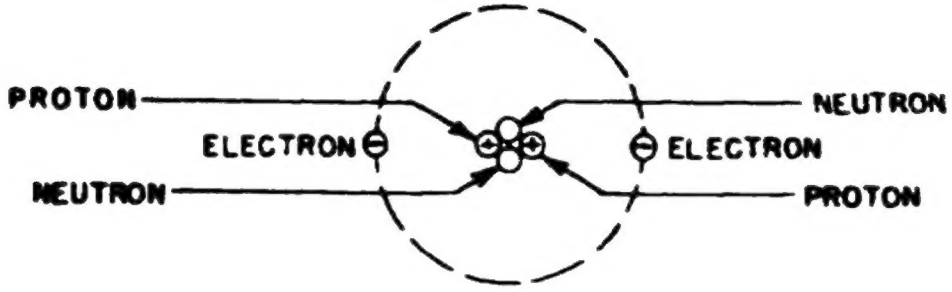


Figure 1. The helium atom.

(2) In some elements, the electrons rotate about the nucleus in different numbers of orbits. It is found that electrons in the outer orbit of some elements are easier to move from one atom to the next than in other elements. It is the movement of these electrons that we call electric current, or simply current.

2. ELECTRICITY

a. Current. Electrons rotate about a nucleus continually in all matter, but in doing so they neither work nor produce any of the effects of electricity. To produce an electrical effect, either some of these electrons must be removed from the atom, or the electrons in a conducting medium must be caused to move from one atom to another in a particular direction. The rate at which electrons move is called current, which is measured in amperes.

(1) Electron movement always takes place from a point of excess electrons (negative charge) toward a point having a deficiency of electrons (positive charge). Since electrons are essentially negative charges, current flow is taken to mean electron movement from a negative charge toward a positive charge. This direction of current flow will be used throughout this subcourse.

(2) Since current flow is based on the movements of electrons, current will flow more easily through materials which have a large number of free electrons. In a material such as copper there are many free electrons. If an external force is used to make the electrons move, great numbers of electrons will be put into motion. Thus it is said that current flows through copper easily, the conductivity of copper is high, or that copper is an electrical conductor.

(3) In a material such as glass there are very few free electrons. If an external force is used to make the electrons move, very few electrons will be put into motion and consequently there will be very little current flow. It is said that substances such as glass are nonconductors, that the conductivity of glass is low, or that substances such as glass are good insulators.

(4) There are no perfect conductors and no perfect insulators. In general. metals are good conductors, while rubber, mica, and glass are good insulators.

(5) The flow of current is evidenced by one of the following effects:

(a) Heat. Current, when flowing through a substance, produces heat. For example, the heating element of an electric toaster becomes red hot when electric current passes through it.

(b) Magnetic. Current flowing through a coil of wire produces a magnetic effect very similar to the effects of an ordinary magnet.

(c) Chemical. Current flowing through a liquid produces a chemical effect. An example of this effect is the charging of a storage battery.

b. Voltage. Current, being electron flow, cannot exist until a force exerts the necessary pressure to move the electrons along the conductor.

(1) In batteries, generators, and other sources of power, an excess of electrons appears at one terminal, while the other terminal has a deficiency of electrons. The terminal that is deficient in electrons exerts an attraction for free electrons, and the terminal with an excess of electrons tends to repel electrons away from it. This combination establishes an electrical force to move the electrons through a conductor. The unit of measurement is the volt.

(2) The terms used to denote this force, or electrical pressure, are electromotive force (EMF), voltage, and, potential difference.

c. Resistance. In all conductors there is some opposition to the movement of electrons. This property, which depends on temperature and dimensions of the conductor, is known as resistance. Resistance becomes a very important property of electrical circuits. Its unit of measure is the ohm.

3. OHM'S LAW

a. Definition. Ohm's law, simply expressed, is as follows: For any dc circuit or part of a circuit under consideration, the current is equal to the EMF divided by the resistance. The following equation expresses the relationship:

$$\text{current} = \text{voltage} \div \text{resistance}$$

or:

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

It is common practice to use the following symbols:

E is voltage

I is current

R is resistance

Using these symbols, Ohm's law may be written:

$$I = \frac{E}{R} \qquad R = \frac{E}{I} \qquad E = I \times R$$

A simple memory aid for this relationship is shown in figure 2. Simply cover the symbol of the desired quantity (I, E, or R), and the relationship of the remaining two quantities will be shown by the circle.

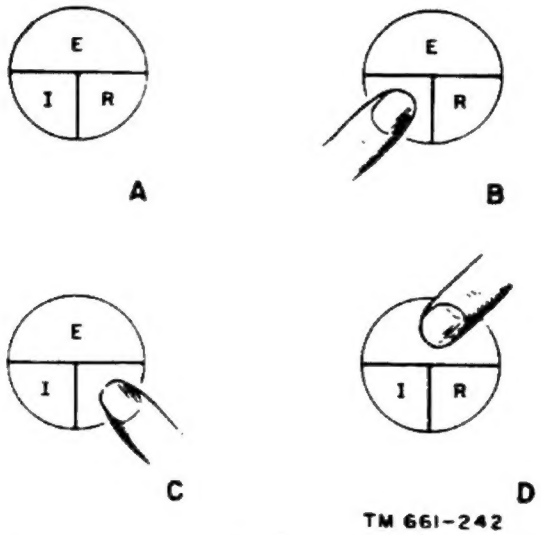


Figure 2. Memory aid for learning Ohm's law.

b. Circuits. To have a flow of current there must be a path, or conductor, in which electrons can move. This conductor must be in the form of a closed loop which provides a continuous path for the flow of current from the negative source of EMF back to the positive side. This closed loop is known as a circuit. Current flow will cease anytime the circuit is broken, but the electrical potential difference will remain across the two points of the break. In every electrical circuit where there is movement of electrons, pressure, resistance, and current are present and must be considered together to understand the circuit clearly. It must be remembered that Ohm's law applies just as much to any particular part of a circuit as it does to the entire circuit.

c. Application of Ohm's Law. Figure 3 is a diagram of a simple series-connected circuit. A conductor connects a 12-volt battery, an ammeter, and a resistor in this simple circuit. The ammeter is placed in series with the circuit to measure current (I), and the voltmeter is placed in parallel with the battery to measure voltage (E). The wire used to connect the various pieces of equipment is considered to have negligible resistance in electrical problems unless a specific value is given. The relationship of I, E, and R in figure 3 is illustrated in the three examples that follow.

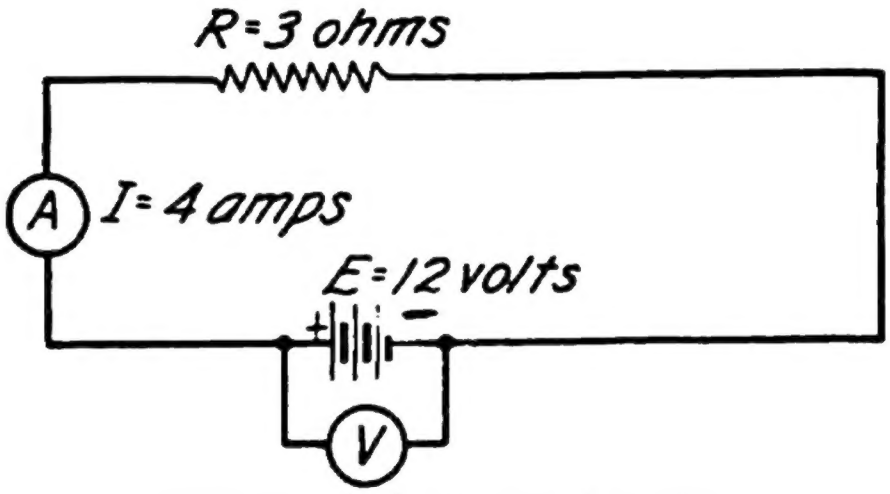


Figure 3. Simple electrical circuit.

Example 1: Find the current when the applied voltage is 12 volts and the resistance is 3 ohms.

$$I = \frac{E}{R} = \frac{12}{3} = 4 \text{ amperes}$$

Example 2: Find the resistance when the voltage is 12 volts and the current is 4 amperes.

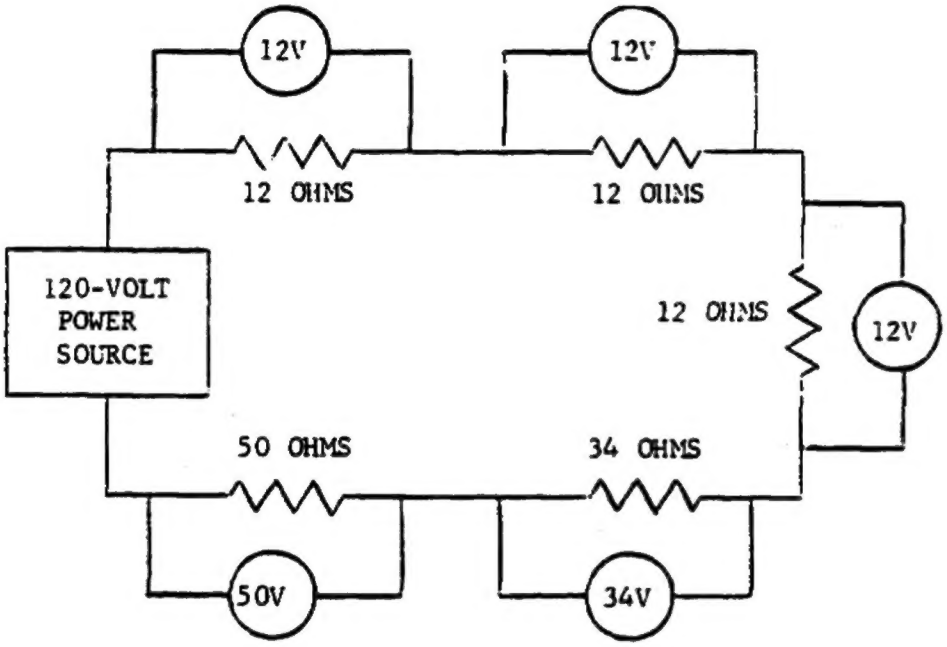
$$R = \frac{E}{I} = \frac{12}{4} = 3 \text{ ohms}$$

Example 3: Find the voltage when the current is 4 amperes and the resistance is 3 ohms.

$$E = I \times R = 4 \times 3 = 12 \text{ volts}$$

4. SERIES CIRCUITS

a. Resistance. A series circuit is one in which the resistances or other electrical devices are connected end to end so that the same current flows in each part of the circuit. Each part of the circuit adds its opposition to the flow of current to the opposition offered by every other part. An example of a series circuit is shown in figure 4. Each resistor opposes the flow of current from the power source. The total opposition is therefore the sum of the resistances of all five resistors. The resistor having the highest resistance value will develop the largest value of voltage across it.



TOTAL RESISTANCE = 12 + 12 + 12 + 34 + 50 = 120 OHMS

$$\text{TOTAL CURRENT} = \frac{\text{TOTAL VOLTAGE}}{\text{TOTAL RESISTANCE}} = \frac{120 \text{ VOLTS}}{120 \text{ OHMS}} = 1 \text{ AMPERE}$$

308-4

Figure 4. Series-resistive circuit.

b. Current. Since all components of the circuit under discussion are in series, it is evident that the same current that flows through any one component flows through all components included within the circuit. The total value of current is therefore proportional to the total opposition to the flow of current and to the applied voltage. It is also evident that the current leaving the circuit must be of the same value as that entering the circuit.

c. Voltage. A certain amount of force is required to move the electrons through each of the resistors. By using a voltmeter, we can measure the force. In the circuit shown in figure 4, voltmeters are placed across each of the resistors and each meter indicates the voltage required to force the current through that particular resistor.

(1) The following voltages are present in this series circuit: 12 volts for each of the 12-ohm resistors, 34 volts for the 34-ohm resistor, and 50 volts for the 50-ohm resistor. When we add these voltages, we find they total 120 volts, the value of the source voltage.

(2) This gives rise to the basic rule: The total of all the voltages developed across the several resistances in a series circuit is always equal to the applied voltage.

(3) The voltage across each resistance is called the voltage drop to signify that the voltage around the circuit gradually decreases as the current travels around the circuit from a given starting point. After the current has made a complete loop of the circuit, the total voltage drop equals the applied voltage.

(4) The voltage occurs only so long as current flows. If current ceases, there is no longer a voltage drop. For example, assume that a resistor burns out. When that happens, current flow ceases, at which time the full applied voltage will appear across the terminals of the burned out resistor.

d. Laws. The three important laws relating to series circuits are:

(1) The total resistance is equal to the sum of the individual resistances.

(2) The same current flows in each part of the circuit.

(3) The sum of the voltages across the individual resistors is equal to the applied voltage.

5. PARALLEL CIRCUITS

A parallel circuit is one in which one terminal of each element is connected to a common point to form one terminal of the system, and the other terminal of each element is connected to a second common point to form the other terminal of the system. The schematic diagram of a parallel circuit is shown in figure 5. This circuit shows three resistors connected in parallel between points a and b.

a. Voltage. In figure 5, the same voltage that is applied to R1 is also applied to R2 and to R3. This is true because the corresponding points of each resistor are connected to the same points, a and b, and the same difference of potential must exist between points a and b for all three resistances.

b. Current. If an additional path through which the current may flow is provided in a circuit, the total current in the circuit must be the original

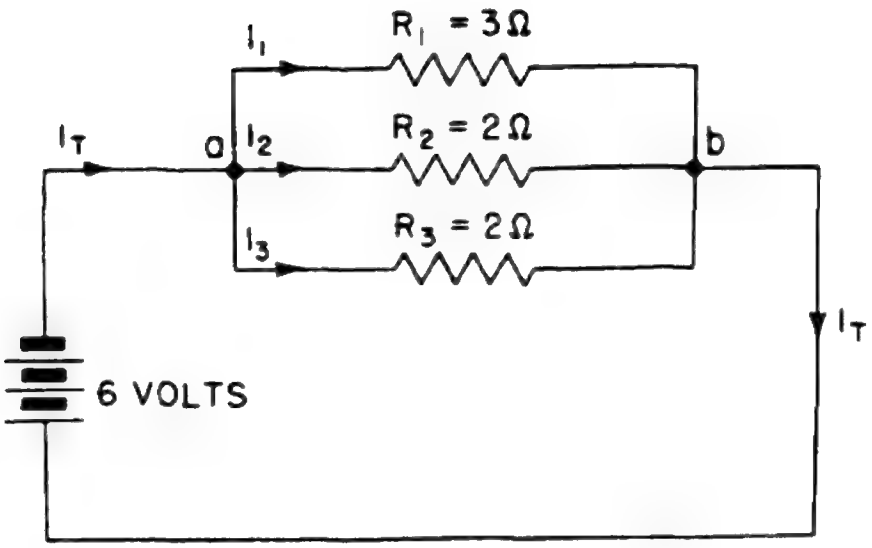


Figure 5. Parallel-resistive circuit.

value plus that of the added path. In figure 5, if only R1 is connected to the 6-volt source, it is known by Ohm's law (I = E/R) that the current is 6/3, or 2 amperes. When R2 is added, the same voltage is applied to it as was applied to R1. The current through R2 must equal 6/2, or 3 amperes. The total current from the source is now 2 plus 3, or 5 amperes. When R3 is added, the total current from the battery will be increased another 3 amperes or will equal 2 plus 3 plus 3, or 8 amperes. The greater the number of branches in a parallel circuit, the greater is the current flow from the source.

c. Resistance. Since the total current in the circuit and the applied voltage are both known, the combined resistance of R1, R2, and R3 may be calculated: R = E/I = 6/8, or 0.75 ohm. Note that the combined resistance is less than the smallest value of any one resistor in the parallel combination.

d. Laws. The three important laws relating to parallel circuits are:

(1) In a parallel circuit the same voltage is applied across each element.

(2) The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.

(3) The combined, or total, resistance of a parallel circuit is equal to the applied voltage divided by the total current.

e. Combining Parallel Resistances.

(1) One method of determining the total resistance of a parallel circuit was shown in c above. This method is satisfactory, provided the

total current is known. If the total current is not known, other means must be used for finding the total resistance. The simplest case is that of several equal resistors connected in parallel. To solve this problem, divide the resistance of one piece of equipment by the number of pieces connected in parallel. If two 10-ohm resistors are connected in parallel, the total resistance offered by the two is 10/2, or 5 ohms. If three 12-ohm resistors are connected in parallel, the total resistance offered by the three resistors is 12/3, or 4 ohms. In other words, the total resistance of equal resistances connected in parallel is equal to one resistance divided by the number connected.

(2) Unfortunately, the different pieces of equipment used in electrical circuits do not have the same resistances. Therefore, they do not all draw the same amount of current when different pieces of equipment are connected across a battery. For such cases, another method has been found for the calculation of the total resistance. Refer to figure 6 which shows two resistors of unequal value placed in parallel across a battery.

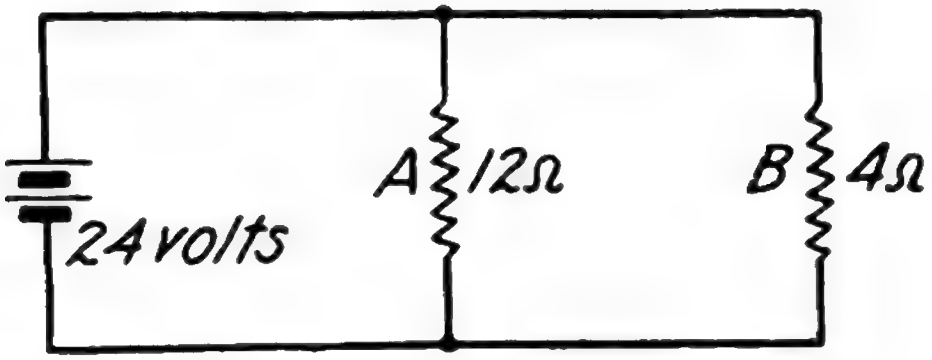


Figure 6. Two unequal resistors connected in parallel.

(3) The most commonly used method of determining the resistance of a parallel circuit is known as the product-over-the-sum method as is shown below.

$$\text{Combined resistance } R = \frac{\text{product}}{\text{sum}} = \frac{A \times B}{A + B} = \frac{12 \times 4}{12 + 4} = \frac{48}{16} = 3 \text{ ohms}$$

6. SERIES-PARALLEL CIRCUITS

Series-parallel circuits consist of groups of parallel resistors in series with other resistors.

a. Solving Series-Parallel Circuits. Series-parallel circuits may be solved by application of the rules already given for simple series and simple parallel circuits. To do this, the series-parallel circuit is reduced to an equivalent, simplified circuit. Each group of parallel resistors is first replaced by its equivalent single resistance, and then the entire circuit is treated as a series circuit. Refer to figure 7.

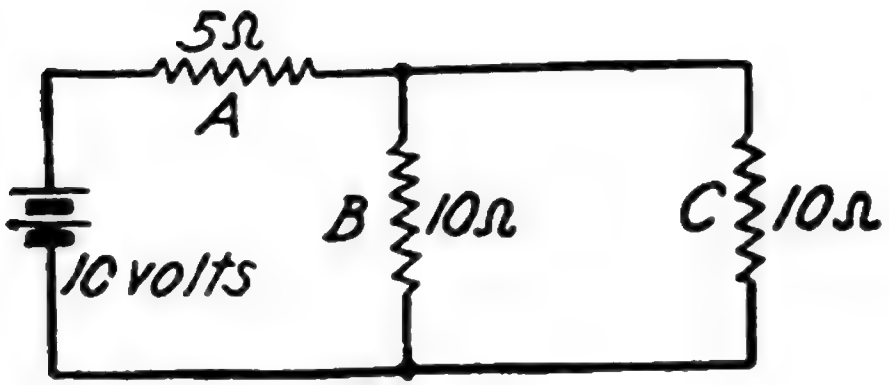


Figure 7. Series-parallel circuit.

(1) The first step is to reduce the two parallel resistors, B and C, to an equivalent single resistance. As B and C are equal, divide 10 by 2, which gives 5 ohms as the total parallel resistance. The circuit is now a simple series circuit of two 5-ohm resistors. The total resistance is obtained by adding the resistance of A to the equivalent resistance of B and C. This gives 5 plus 5, or 10 ohms, as the resistance for the entire circuit.

(2) The total current is calculated by means of Ohm's law:

Total current I = E/R total = 10/10 = 1 ampere.

(3) This 1 ampere flows through resistor A, giving a voltage drop of 5 volts. As the two parallel resistances have the same value, the 1 ampere of current divides equally between the two. The voltage drop across B equals I x R = 1/2 ampere times 10 ohms, or 5 volts. Since resistors B and C are parallel, this is also the voltage drop across resistor C.

(4) Following one complete path around the circuit, you can see that the sum of the voltage drops is equal to the applied voltage. Starting from the positive side of the battery there is a 5-volt drop across resistor A, another 5-volt drop across resistor B, and back to the battery. Following a path through resistor C will yield the same results. Care must be taken to follow only one path at a time when tracing through a circuit.

b. Sample Calculation. Refer to figure 8.

(1) Resistors V and W in series yield a total resistance of 10 ohms.

(2) Resistor B in parallel with series resistors V and W yields a parallel resistance of 5 ohms.

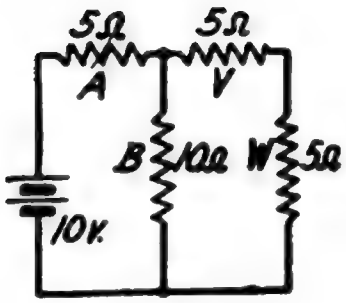


Figure 8. Sample series-parallel circuit.

(3) The parallel resistance of 5 ohms is added to resistor A in series with the parallel combination to yield 10 ohms total.

(4) Using Ohm's law, you can now determine the voltage drop across any one resistor in question.

7. ELECTRICAL POWER

Electrical power is the time rate at which work is done by an electrical device. Of greatest concern in electrical circuits is the power loss which occurs when heat is generated by current flowing through a resistance. The heat is usually dissipated into the air and lost, but can be utilized as in the case of light bulbs to produce light, soldering irons to produce heat, or filaments of electron tubes to produce electron clouds.

a. The Watt. The watt is the unit of electrical power and is equivalent to 1 ampere of current at a pressure (EMF) of 1 volt. In mathematical terms, power is equal to current times voltage. By the use of this formula, the power in an electrical device can be determined if the current and voltage are known. Other formulas can be used to determine power if current and resistance are known. By simple algebraic conversions of these formulas, the third (unknown) quantity can be determined if two quantities are known.

b. Sample Problems. In using the formulas for finding the total power and the power loss of a circuit, certain items should be noted. To find the total power in a circuit, we use the formula $P = EI$. Thus, to find the power of the entire circuit, the total circuit current and total circuit voltage must be known. On the other hand, a combination of the power formula with Ohm's law will give the power in a particular part of the circuit or the entire circuit. This combination, therefore, gives us the formulas $P = I^2R$ and $P = E^2/R$ for computing the power in a circuit. If it is desired to compute the power loss in only one part of a circuit, the current and the voltage drop in that part of the circuit must first be known. It is important to notice that a small increase in current (I) can give a large increase in power (P). For example, doubling the current yields four times the power.

P = power in the circuit in watts.

E = EMF supplied to the circuit in volts.

I = current flowing in the circuit in amperes.

R = resistance of the circuit in ohms.

Example 1: What is the power in a 10-ohm circuit that is drawing 2 amperes of current?

$P = I^2R = 2^2 \times 10 = 4 \times 10 = 40$ watts.

Example 2: A 20-ohm resistor is required to drop the 12-volt battery voltage of a vehicle to 6 volts for the lighting of a t-volt radio tube. What is the power at the 20-ohm resistor?

$P = E^2/R = (6\text{-volt drop})^2/20 = 36/20 = 1.8$ watts.

Example 3: A 1,200-watt electric soldering iron is connected to a 120-volt power source. How much current will the iron draw?

$I = P/E = 1,200/120 = 10$ amperes.

c. Power Losses.

(1) Most of the heat loss (power loss) in communication equipment occurs in electron tube filaments. In a man-pack radio set, the battery must furnish the power required to heat the filaments of the tubes. This necessitates the use of heavy and cumbersome battery packs. One of the reasons that radio sets using transistor circuits are smaller and lighter is that the transistors, having no filaments as tubes do, consume far less power. The battery can therefore be smaller and lighter in weight.

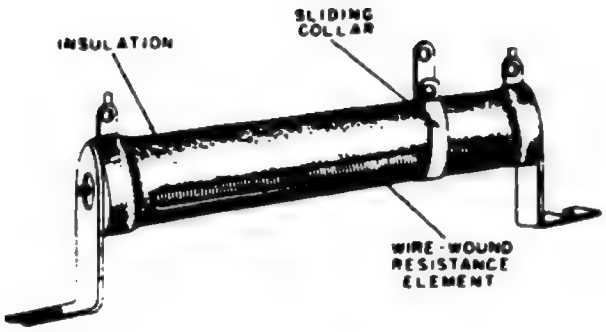
(2) Power loss due to resistance is an important consideration in communication work. The resistor used must be capable of radiating the heat generated without becoming hot enough to burn insulation or to start fires. For this reason, resistors are rated in watts as well as in ohms. This wattage rating indicates the amount of current that the resistor can conduct without becoming damaged by heat. When resistors are inclosed, the heat they radiate may cause troubles in other parts of the equipment.

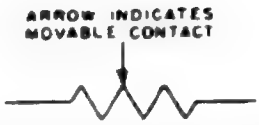
8. RESISTORS

A resistor is a circuit element designed to introduce resistance into the circuit for the purpose of reducing or controlling the flow of current. Resistors may be divided into three general types, according to their construction. These are known as fixed resistors, adjustable resistors, and variable resistors.

a. Fixed Resistors. Fixed resistors are used to introduce constant values of resistance into circuits. For low-power requirements (up to 20 watts), small carbon or metalized resistors are used; with heavier power requirements, larger resistors of wire-wound construction are employed. Several types of fixed resistors are shown in figure 9.

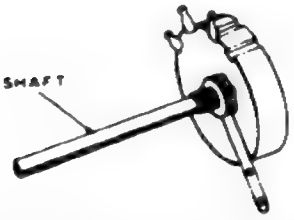
Figure 9. Types of fixed resistors.





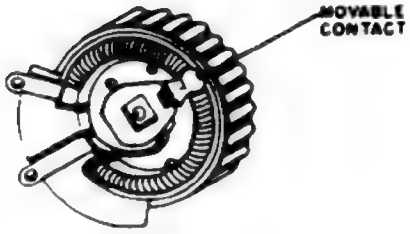
ADJUSTABLE RESISTOR AND SYMBOL

A



VARIABLE RESISTOR (POTENTIOMETER) AND SYMBOL

B



VARIABLE RESISTOR (RHEOSTAT) AND SYMBOL

C

TM 661-41

Figure 10. Adjustable and variable resistors.

b. Adjustable Resistors. Adjustable resistors are used where it is necessary to change or adjust the value of the resistance in a circuit from time to time. In its usual form, the adjustable resistor is wire wound, and has one or more sliding collars which may be moved along the resistance element to select any desired resistance value (A of fig. 10). The collar is then clamped in place.

c. Variable Resistors. Variable resistors are used in a circuit when a resistance value must be changed frequently. Depending on the power requirements, variable resistors are either of carbon or wire-wound construction. The actual resistance element of the variable resistor is usually circular in shape, and the sliding tap or "arm" which makes contact with it is provided with a knob and a shaft by means of which the resistance can be changed smoothly.

(1) If both ends of the resistance element are provided with terminals (in addition to the sliding arm). the variable resistor is called a potentiometer (B of fig. 10).

(2) If only one end of the resistance element and the sliding arm are brought out to connection terminals, the variable resistor is called a rheostat. A rheostat is shown in C of figure 10. Current flows only through the section of the resistance element included between the sliding arm and the connecting and the connecting terminal.

9. MAGNETISM

Magnetism plays a most important role in electricity and electronics. Practically all electrical power is generated, distributed, and used through the medium of magnetism. Power generators, transformers, and motors have magnetism as their basis of operation. The radio transmitter that develops a signal, the antenna that radiates it, the antenna that receives it, and the radio receiver that delivers the sound--these too function on the basis of magnetism. It is therefore necessary that we understand some of the principles of magnetism if we want to understand some of the principles of electricity and electronics.

a. Magnetic Field. If we were to take a bar magnet, lay a piece of glass on top of it, and then sprinkle iron filings on the glass, we would find that the filings would become arranged in curved lines as shown in A of figure 11. These curved lines, extending from the two poles of the magnet (north and south), follow the magnetic lines of force surrounding the magnet. (Every magnet will have a north and a south pole.) These lines of force are shown in B of figure 11. Note that the concentration of iron filings is greatest at the ends of the magnet, showing that the lines of force have their greatest concentration at these ends. The magnetic lines of force are said to pass from the north (N) to the south (S) pole, and return through the body of the magnet.

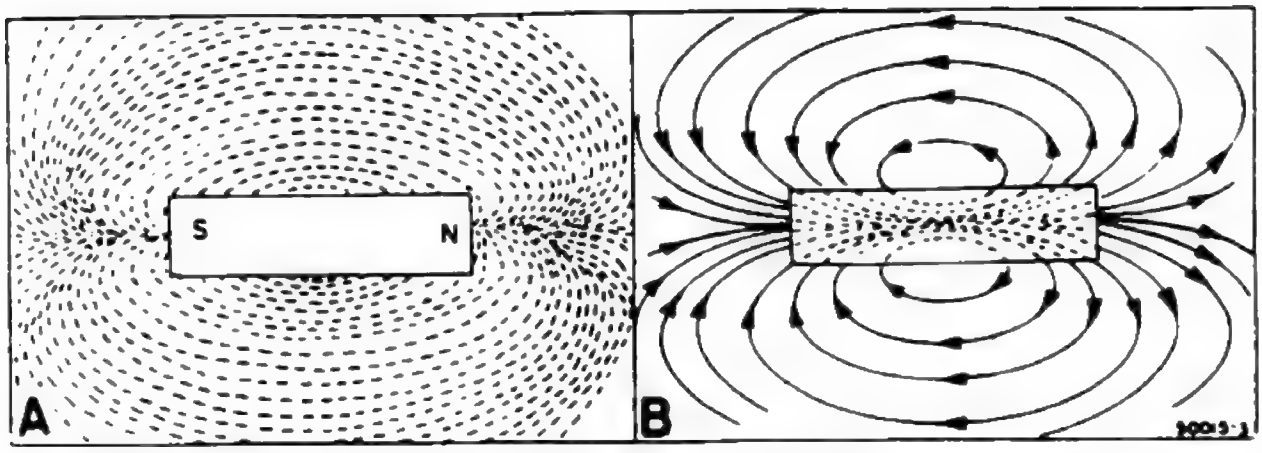


Figure 11. Magnetic lines of force traced by iron filings.

b. Characteristics of Permanent Magnets. A permanent magnet is usually a bar of steel that has been magnetized. This bar may be made into any convenient shape to satisfy the needs of the device. By bending the bar around in a horseshoe shape, the lines of force can be concentrated in a smaller space than is the case with a bar magnet. Most useful magnets have some variation of a horseshoe configuration.

(1) Like poles repel, and unlike poles attract. This can be proved by the simple experiment using bar magnets as shown in figure 12. The magnets will not touch when N and N poles are presented to each

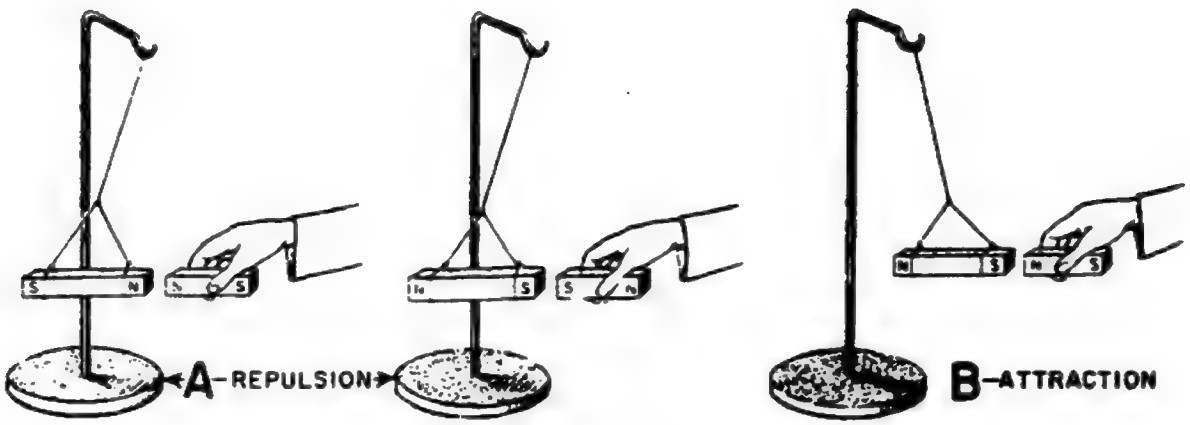


Figure 12. Like poles repel, unlike poles attract.

other, nor when S and S poles are presented to each other. They will touch, however, when N and S poles are presented to each other.

(2) When unlike poles are brought close to each other, the magnetic lines of force pass from the K pole of one magnet to the S pole of the other. These lines of force of the two magnets join together and try to pull the two poles together. On the other hand, when like poles are presented to each other, the lines of force will not join together, and consequently develop a pushing rather than an attracting effect.

10. ELECTROMAGNETISM

a. The flow of electrons in a conductor always produces a magnetic field. In the wire shown in A of figure 13, current flow causes lines of force to encircle the wire.

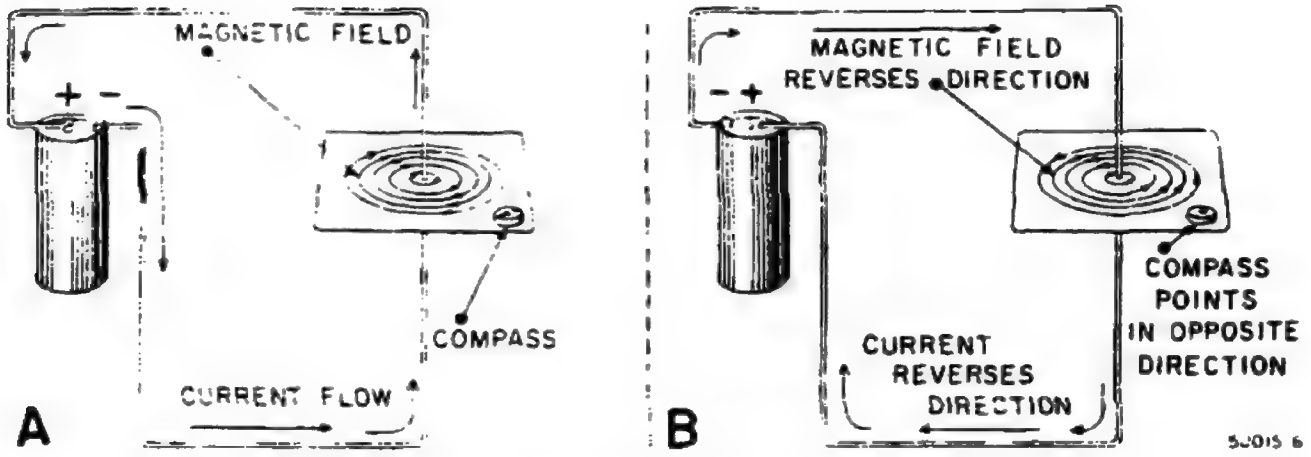


Figure 13. An electric current produces a magnetic field.

(1) The direction of current determines the path the lines of force take in encircling the wire. The compass indicates the direction of the lines of force.

(2) The concentration of lines of force (flux density) in the space surrounding the wire is proportional to the strength of the current flow. The greater the current, the greater is the flux density.

(3) A reversal in the direction of current flow causes a reversal in the direction of the lines of force. In B of figure 13, the compass reflects the change that takes place.

(4) When, for any reason, the current decreases, the lines of force "collapse" toward the wire. The number of lines of force remaining is proportional to the remaining current flow. If the current drops to zero, the lines of force will disappear. The rate at which the lines of force build up or collapse is determined primarily by the rate of change of current in the wire.

(5) Unless energy in the magnetic field is absorbed by another circuit, when current flow ceases all the energy set up in the magnetic field returns to the circuit that originally set up the field.

b. The magnetic field produced by current flowing in a single loop of wire is very weak. If two loops are made in the conductor, the lines of force will circle the two loops (A of fig. 14). The magnetic field will be twice as strong as with one loop since the lines of force of the two loops combine.

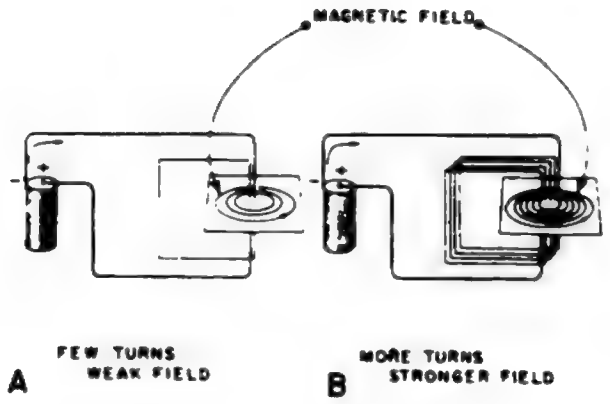


Figure 14. Adding more loops increases the strength of the magnetic field.

(1) If a still stronger magnetic field is desired, additional turns can be added to the coil of wire. The lines of force show a greater concentration in the magnetic field shown in B of figure 14.

(2) By placing a magnetic substance such as iron or steel in the center of the coil, the number of lines of force can be concentrated into a smaller area. This condition comes about because there is less opposition to magnetic lines of force in magnetic materials than in air.

(3) The magnetic flux can also be conveniently controlled by varying the amount of current flowing through the wire. One measure of the holding power of an electromagnet is the number of ampere turns (number of amperes multiplied by number of turns).

c. Lines of force in the magnetic field of a coil of wire exhibit the same characteristics as shown by a magnet; that is, N and S magnetic poles develop at the ends of the coil, and the lines of force form continuous loops through the coil. A coil of wire having a soft iron core and current flowing through the wire is therefore called an electromagnet. Electromagnets form the basis of all electric motors and generators, doorbells, most types of electrical indicating instruments, transformers, tuning coils, and many more devices.

11. ELECTROMAGNETIC INDUCTION

a. Current can be induced to flow in a conductor if the conductor is moved through a stationary magnetic field or if the field is moved so that the lines of force cut a stationary conductor.

(1) The wire in A of figure 15 is moved downward through the magnetic field between the two magnetic poles. As it moves downward, cutting the lines of force, current is induced in it.

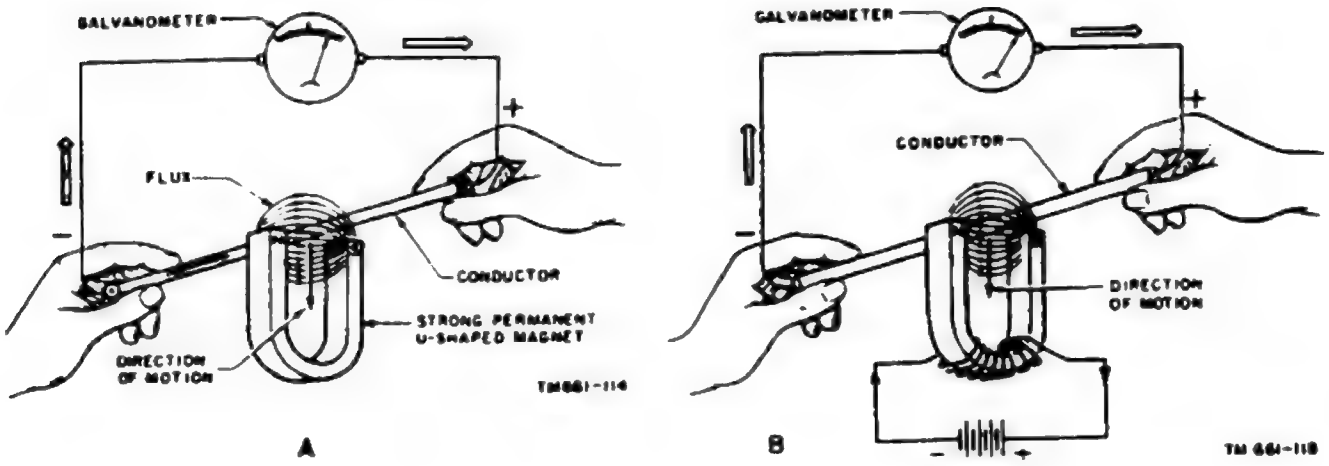


Figure 15. Induced current flow.

(2) The direction of current is indicated by the arrows and the movement of the zero center-scale meter (galvanometer). When the movement is reversed, the galvanometer will indicate a current flow in the opposite direction.

(3) If the wire is held stationary and the magnetic field is moved, the effect is the same; that is, current will be induced in the wire. All that is required is that there be relative movement between the two so that the lines of force are cut by the wire.

(4) By changing the permanent magnet to an electromagnet, as shown in B of figure 15, it is possible to increase the flux density to develop a higher induced current in the conductor. Note the increased reading of the galvanometer. A further advantage is obtained with this

system in that the magnetic flux density can be varied at will simply by varying the battery voltage or by controlling the current through the coil of wire.

(5) Mention has been made of the value of induced current. Actually, it is the voltage that is induced in the wire passing through a magnetic field. It is this induced voltage that pushes current around the circuit.

b. The magnetic field can be moved by physically moving the magnet or, if it is a magnetic field from an electromagnet, it can be moved by starting and stopping the current flow in the electromagnet.

(1) In B of figure 15, when the coil of wire is attached to the battery, current starts to flow through it. This current, as it starts to flow, builds up a magnetic field. This magnetic field might be considered to be expanding (like a balloon, in a sense) and moving out from the electromagnet. As the field moves outward, its lines of force will cut through the wire held close to the electromagnet. This wire will therefore have voltage induced in it.

(2) If the electromagnet is disconnected from the battery, its magnetic field will collapse and disappear. As this happens, the lines of force move inward toward the electromagnet. Again, the wire held close to the electromagnet will be cut by moving lines of force and will have a voltage induced in it. This time, the lines of force are moving in the opposite direction, and the wire will, therefore, have voltage induced in it in the opposite direction.

(3) It can thus be seen that voltage can be induced in the wire by three methods: the wire can be moved through a stationary magnetic field, the wire can be held stationary and the magnet can be moved so the field is carried past the wire, or the wire and electromagnet can both be held stationary and the current through the electromagnet be turned on and off so that the expanding and collapsing magnetic field moves across the wire.

c. The amount of EMF induced in a conductor moving in a magnetic field depends on four factors:

(1) The strength of the field.

(2) The length of the conductor cutting the field, or the size and number of turns in a coil when the conductor is wound in the form of a coil.

(3) The speed at which the conductor sweeps through the magnetic field, or the speed of rotation of a coil in a magnetic field.

(4) The angle at which the conductor passes through the lines of force.

d. Since the armature of an electric generator is composed of many turns of wire and electromagnets make up its stator, it follows that the output voltage will depend on the above four factors. The most practical method of

controlling the generator output voltage is to vary the current through the windings of the electromagnets and thus vary the strength of the field.

12. ALTERNATING CURRENT

When we use rotating mechanical devices to produce the large amounts of current needed for practical uses, we find that the mechanical devices produce essentially an alternating current (ac); that is, the current flows first one way and then reverses itself and flows the other way through the conductor. The simplest source of mechanically produced ac energy is the ac generator. It produces this energy by a combination of electromagnets and rotating coils of wire.

a. Basic Ac Generator. The basic ac generator is made up of an electromagnet that sets up a strong magnetic field between two pole pieces. The coil of wire then spins between these two pole pieces to develop a voltage as a result of the wire cutting the lines of force in the magnetic field. The ends of the coil of wire are brought out to sliprings so that the voltage developed by the coil may be conveniently attached to circuits that will use the voltage. The circuits so connected are collectively called the load. The sliprings of a basic ac generator are shown connected to a galvanometer in figure 16. This instrument will measure the amount and direction of the current developed by the generator.

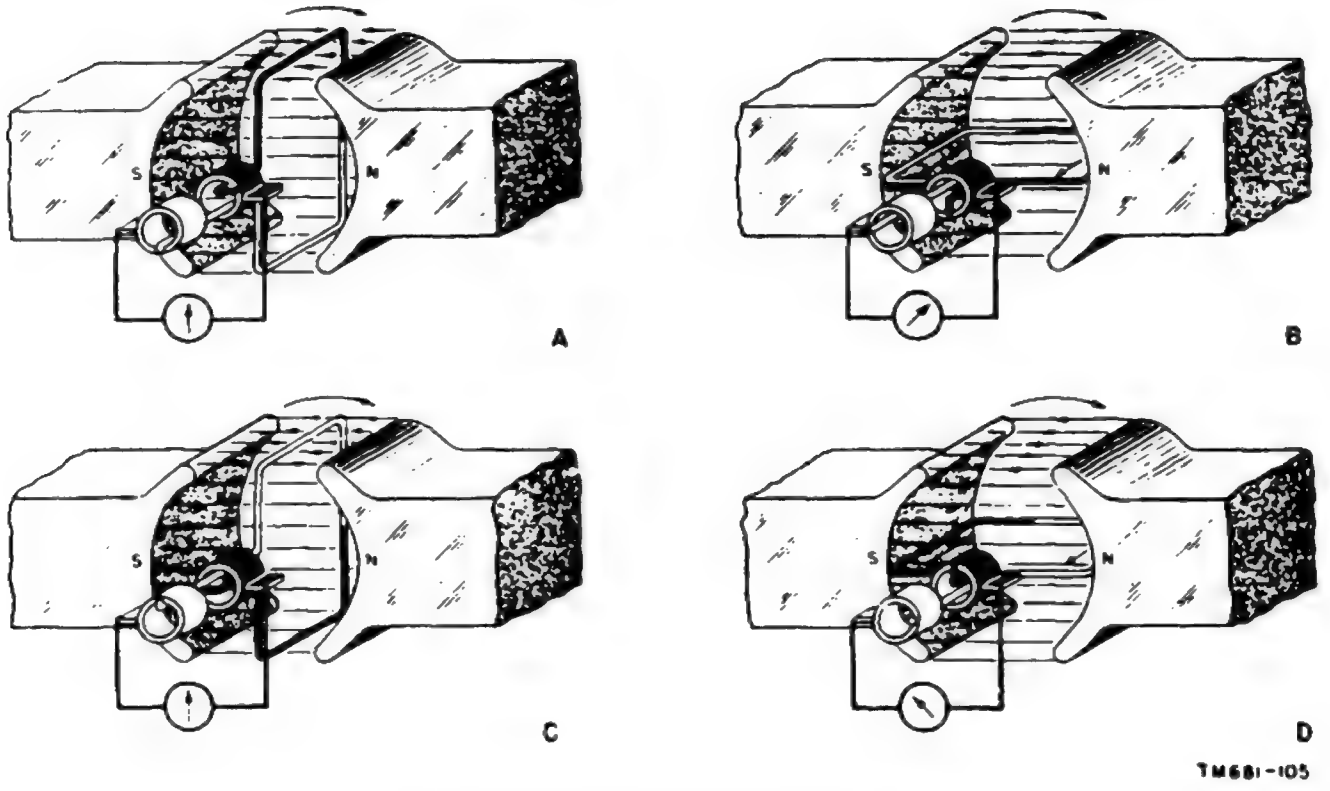


Figure 16. Generation of ac voltage.

b. Principles of Operation. Consider the four positions of the single-turn loop and sliprings as they rotate clockwise in a uniform magnetic field produced by the poles of an electromagnet.

(1) When the loop rotates through the position shown in A of figure 16, the black coil side is moving toward the north pole and the white side is moving toward the south pole. Because the coil sides are moving parallel to the direction of the field, no flux lines are cut and the EMF induced in the loop is zero. This is indicated by the galvanometer connected to the stationary carbon brushes which contact the sliprings.

(2) After the loop has rotated 90° from its initial position and is passing through the position shown in B of figure 16, the black coil side is moving downward and the white side upward. Both sides are cutting a maximum number of flux lines and the induced EMF, as indicated by the meter, is at a positive maximum. (Meter reads to the right on positive voltage in this case.)

(3) As the loop passes through an angle of 180° in C of figure 16, the coil sides again are cutting no flux lines and the generated EMF is again zero.

(4) As the loop passes through an angle of 270°, as in D of figure 16, the coil sides are cutting a maximum number of flux lines and the generated EMF is at a negative maximum.

(5) The next 90° revolution of the loop completes the 360° revolution, and the generated EMF falls to zero.

(6) The preceding facts may be summarized as follows: As the loop makes one complete revolution of 360°, the generated EMF passes from zero to a positive maximum, to zero, to a negative maximum, and back to zero. If a constant speed of rotation is assumed, the EMF is said to be periodic. That is, the values of EMF repeat at regular intervals, and can be represented by a sine wave when shown on a graph. Figure 17 contains a graph that shows the portion of a sine wave representing the EMF produced in one revolution of a wire loop in a magnetic field. This portion is one cycle of the voltage. Note that the

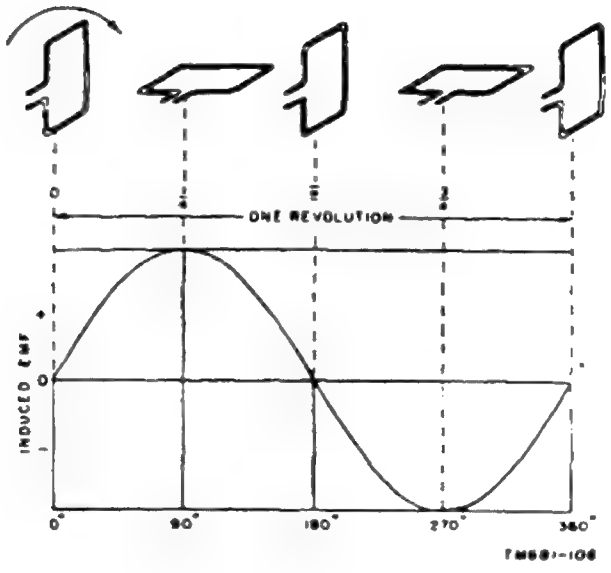
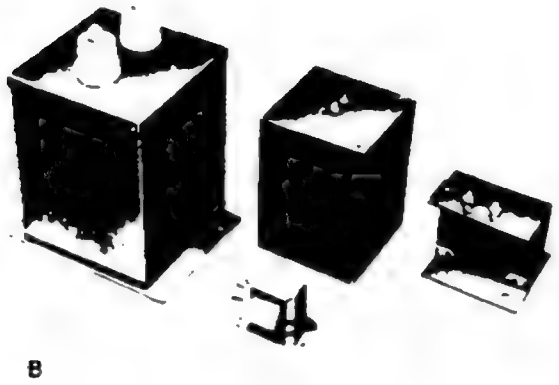


Figure 17. Generation of a sine wave.



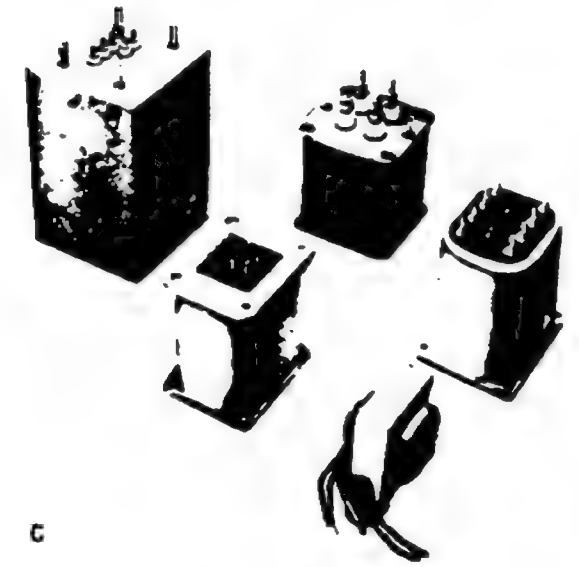


Figure 18. Some types of inductors used in radio circuits.

waveform will be repeated as the loop continues to rotate in the magnetic field, and the number of cycles that occur in a given period of time will depend on the speed at which the loop is rotated. The number of cycles that occur in a given period of time is called the frequency. The unit of frequency is the Hertz (Hz), which is one cycle per second. Two prefixes are used in referring to the higher frequencies. For example:

1 kilohertz (kHz) = 1,000 Hz

1 megahertz (MHz) = 1,000,000 Hz

13. AC CIRCUIT COMPONENTS

Resistance in a circuit restricts the flow of both ac and dc. However, in ac circuits there is an opposition to the flow of current in addition to the resistance of the circuit. This opposition to ac is offered by inductors and capacitors in the circuit.

a. Inductors. Inductors appear in many types and sizes, depending on the application. Regardless of their size and shape, they all consist of turns of wire, or copper tubing. Some have iron cores, and others are hollow (air cores). Their construction depends on the task to be performed.

(1) Most of the coils used in radio work are fixed inductors, which have a constant value of inductance in a circuit. Coils that are hollow (air core) are usually designed to handle alternating voltages at radio frequencies,

while coils having iron cores are usually designed to operate at lower frequencies such as audio or power frequencies.

(2) Inductors having more than one winding are usually called transformers. Their purpose is to physically isolate one circuit from another, and to step up or step down the voltage fed into the winding called the primary winding. Voltage for the circuit or is then taken from the secondary winding.

(3) Samples of air-core and iron-core (magnetic-core) inductors, and iron-core transformers are shown respectively in A, B, and C of figure 18.

(4) Examples of the schematic symbols for these inductors can be seen in figure 19. The air-core transformer in sketch A are for passing radio frequencies. Sketch B shows an iron-core transformer. Sketch C is the schematic symbol for an iron-core inductor, and sketch D is the symbol for an air-core inductor.

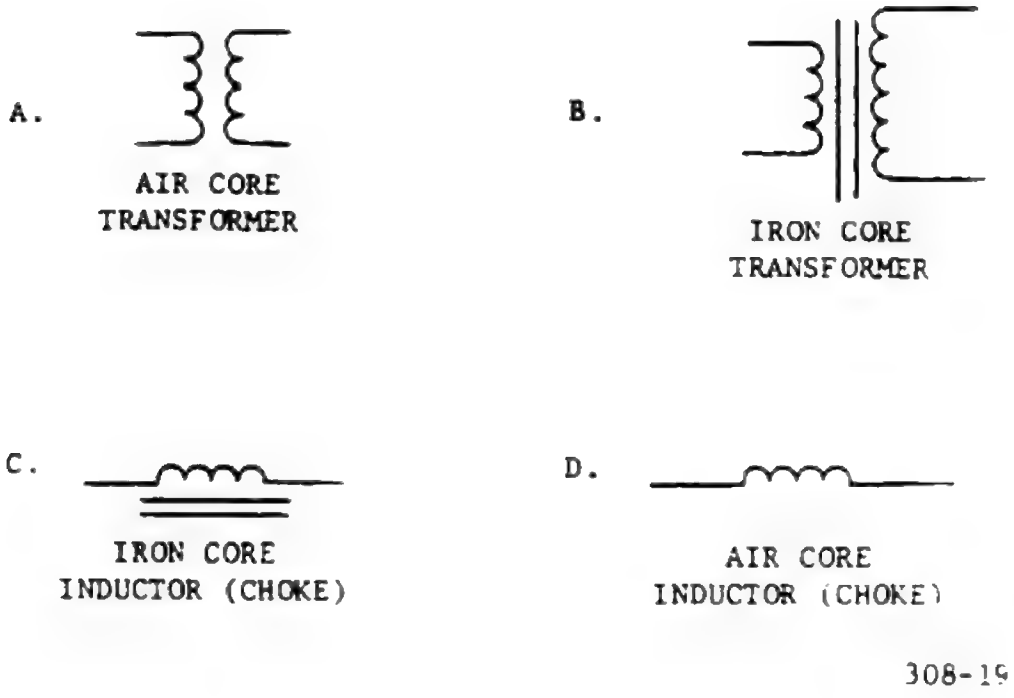


Figure 19. Schematic symbols for inductors and transformers.

b. Capacitors. Capacitors appear in many types and sizes, depending on the circuit application. Most capacitors are fixed in value, but those required for tuning applications in transmitters and receivers are made variable. The construction of capacitors is similar in all types in that metallic plates are separated by an insulating material called the dielectric. In variable types, the dielectric is usually air, but in the fixed types, many substances are suitable for dielectric use. Paper, mica, oil, and chemicals (electrolytic) serve as dielectrics in different types of capacitors, the type of dielectric being chosen to suit requirements of polarity and amount of the voltage applied to the capacitors.

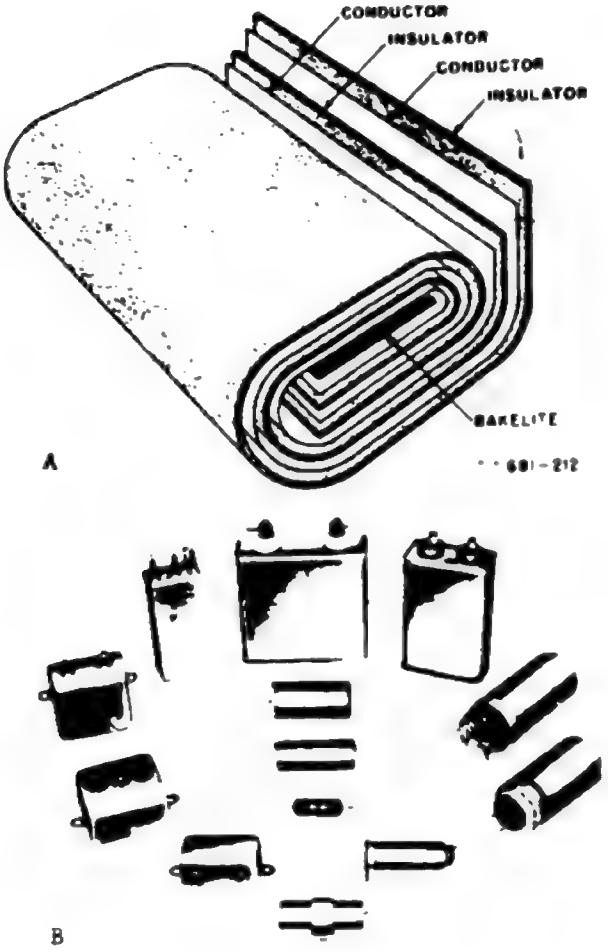


Figure 20. Paper capacitors.

(1) The internal construction of a paper capacitor is illustrated in A of figure 20 with the physical appearance of some types shown in B of that figure. The "pigtails" of wire or terminals of the capacitors are fastened to the sheets of conducting material.

(2) Representative types of mica and ceramic capacitors, electrolytic capacitors, and variable capacitors are shown respectively in A, B, and C of figure 21. The plates of the rotor, or movable element of a tuning type of variable capacitor, slides in between the plates of the stator. These plates are separated by air serving as the dielectric.

(3) Examples of schematic symbols for capacitors can be seen in figure 22. From the symbol, it is not possible to determine the type of dielectric used. The only distinguishable feature is that the capacitor is either fixed or variable. Sketch A indicates a fixed capacitor. Sketch B indicates a variable capacitor. Sketch C shows two variable capacitors which are tuned by the same control knob. When this occurs, the capacitors are said to be ganged and may be located in different circuits. Generally the largest capacitors are used in the power supply since they operate at power frequencies. The next largest are in the audio circuits. The capacitors used in radio-frequency circuits are generally small in comparison with those used at lower frequencies.

14. OPERATION OF INDUCTORS IN AC CIRCUITS

a. Counter Electromotive Force. As stated previously. In ac circuits there is an opposition to the flow of current besides the resistance of the circuit. This additional opposition is caused by the back or counter electromotive force, so named to distinguish it from the applied voltage, which is the original force tending to set up a current flow.

(1) In an ac circuit, the current continually changes amplitude and periodically reverses direction. Any such change causes an expansion or contraction of the magnetic field. The lines of force in this changing field cut the turns of wire in the coil, inducing a voltage which opposes the applied ac voltage that is pushing the current through the windings of the coil. The property of a coil to develop an opposing voltage is known as self-inductance.

(2) Direct application of self-inductance can be seen in a radio-frequency (RF) choke coil. The five smaller coils in A of figure 18 are examples of RF choke coils. Their function is to oppose the flow of RF current, but at the same time allow the passage of dc. They are widely used in radio transmitters.

b. Effect of Inductance. The magnitude (amount) of counter EMF produced by the self-inductance of a coil depends on two factors: the number of turns in the coil and the frequency of the applied voltage.

(1) The number of turns in the coil determines the physical property of inductance. The greater the number of turns, the larger the inductance of the coil. And, of course, the larger the inductance, the more counter EMF is produced.

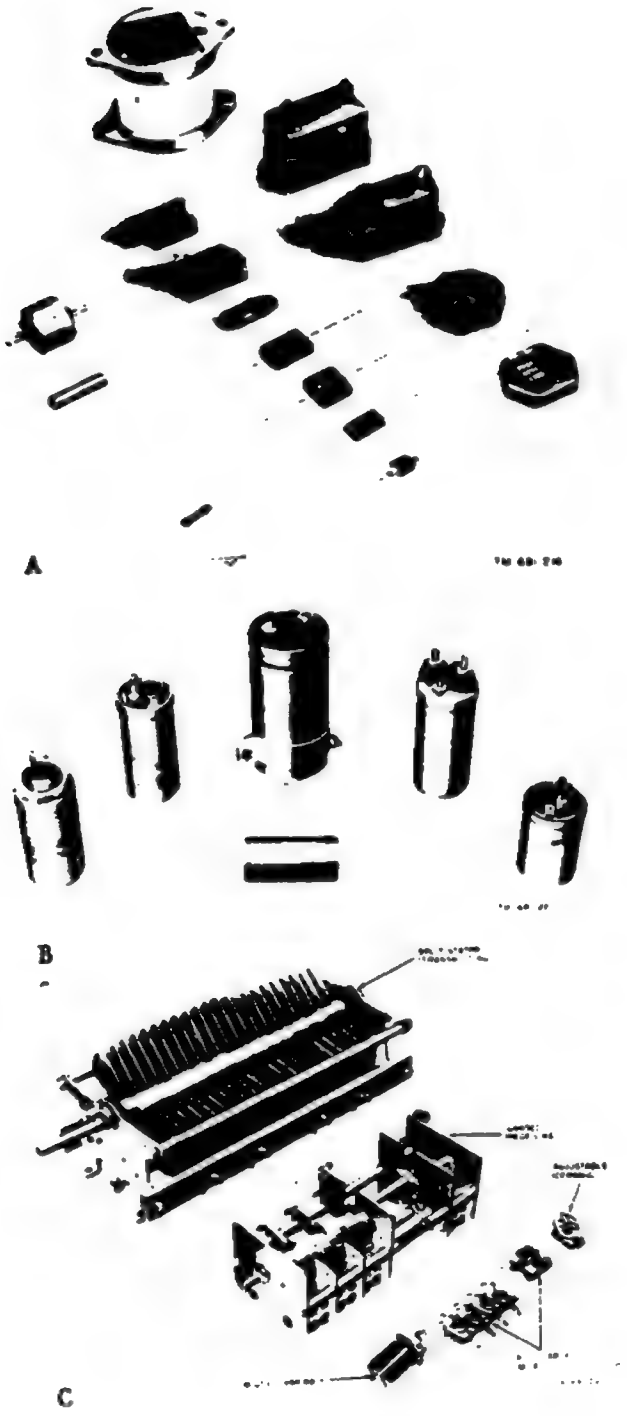


Figure 21. Representative capacitor types.

(2) Since the counter EMF voltage produced by the self-inductance of a coil depends upon the rate at which the lines of force cut the turns, it follows that the higher the cutting rate, the greater will be the

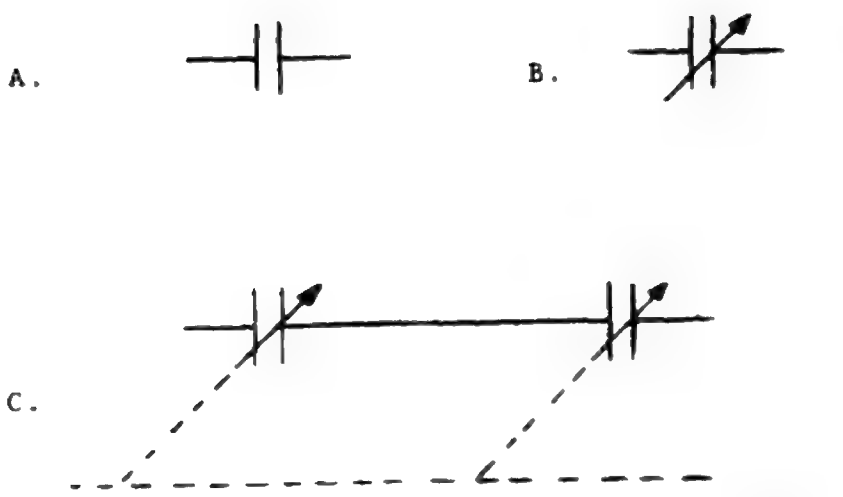


Figure 22. Schematic symbols for capacitors.

counter EMF produced. The rate of change of the magnetic flux is controlled by the frequency of the applied voltage. A coil intended to be used at high frequencies can therefore be smaller than one intended for low frequencies for the same amount of opposition (counter EMF) to current flow. The difference in size of the coils will be evident if you have occasion to compare the RF inductors of a television receiver with those in a broadcast radio receiver.

(3) In the foregoing discussions, the opposition offered to a specific change of ac by an inductance was measured at any given instant in terms of counter EMF, the voltage opposing the applied voltage. In dc circuits, however, any opposition to current flow is termed resistance and is measured in ohms. In ac circuits, therefore, it is convenient to measure inductive opposition in ohms rather than in volts of counter EMF. This type of ac opposition is called inductive reactance and is assigned the symbol X_L to distinguish it from dc resistance, R. From here on, we will refer to the opposition offered by an inductance to ac flow as inductive reactance X_L.

(4) The unit of measure of inductance is the henry (h). Since small values of inductance are used in radio circuits, it is customary to rate the inductance value in millihenries or microhenries.

(a) 1 millihenry = 1/1,000 henry = 0.001 henry = 1×10^{-3} henry.

(b) 1 microhenry = 1/1,000,000 henry = 0.000,001 henry = 1×10^{-6} henry.

(5) Current through an inductance does not increase in proportion to the change of voltage across the inductance. This is due to the fact that a time delay exists in the buildup of the magnetic field to the maximum value. To explain this delay time, it is customary to say

that the current lags, or trails the voltage. In other words, the current through the coil changes somewhat after the time the voltage across the coil changes.

(6) If the ac voltage is varied in frequency from low to high, it will be found that X_L increases in proportion to the increase in frequency.

15. OPERATION OF CAPACITORS IN AC CIRCUITS

The opposition to a change of current through an inductor results from a change in that current. In other words, an inductor tends to oppose any change in current flow. A capacitor develops a counter EMF too, not as the result of a current change, but as the result of a voltage change; that is, a capacitor tends to oppose any change in the applied voltage. Therein lies the basic difference in the operation of these two components in ac circuits.

a. Voltage Across a Capacitor. As illustrated earlier, a capacitor consists essentially of two conducting plates separated by an insulating dielectric. Because of the absence of an electrical connection between the plates, current does not flow through a capacitor. Nevertheless, we know that a capacitor appears to pass a radio signal. How does this take place? Its secret of operation lies in the polarity change that takes place across a capacitor.

(1) Assume that an ac generator is placed in series with a capacitor as shown in figure 23. Assume further that the generator output voltage has the waveform shown in figure 17. The generator output voltage varies from 0 at 0° rotation to maximum positive at 90°, to 0 at 180°, to maximum negative at 270°, and again to 0 at 360°.

(2) At 0°, the distribution of voltage across the capacitor is uniform (no polarity). As the voltage changes through one complete cycle, the polarity changes across the capacitor. Electrons are drawn from one plate of the capacitor by the positive charge developed by the generator. These electrons are forced around the circuit by the generator and deposited on the opposite plate of the capacitor. Then, as the generator output voltage swings to the opposite polarity, the reverse action occurs. The changing polarity across the capacitor in figure 23 is related to the angular degree of generator rotation for one complete cycle of the generator output waveform.

(3) Electron flow is equivalent to current flow. Therefore, current starts to flow around the circuit at the instant that the voltage starts to change across the capacitor. However, the capacitor will not assume maximum charge immediately; it takes a little time. It is therefore customary to say that current through a capacitor leads the applied voltage.

b. Capacitive Reactance. Note that the capacitor develops a voltage that is in opposition to the generator output voltage polarity. This is the counter EMF developed by the capacitor; this is also the opposition that a capacitor offers to the flow of current in an ac circuit. We call this opposition

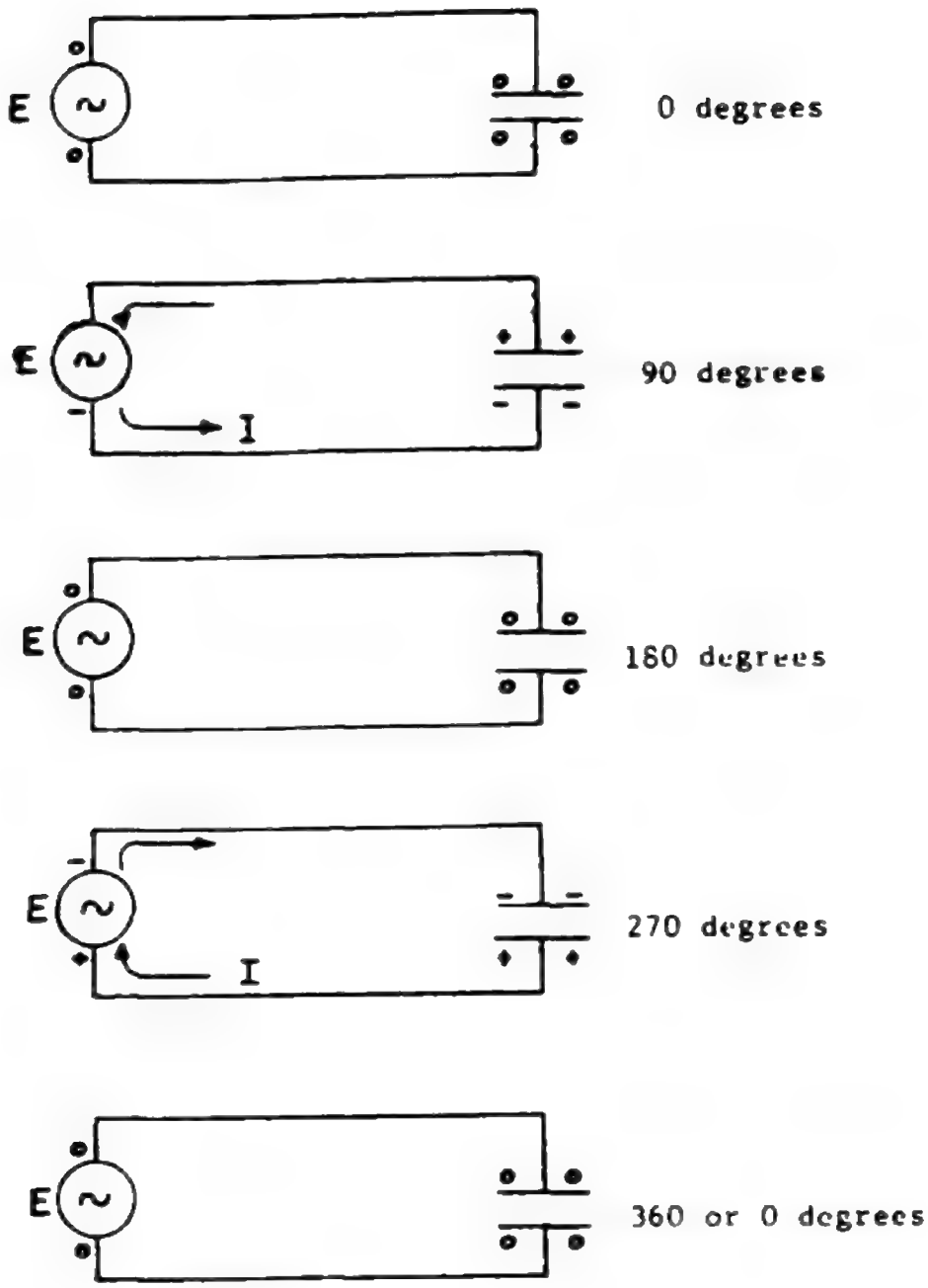


Figure 23. Voltage across a capacitor in an ac circuit.

capacitive reactance, and give it a symbol X_C. If the input frequency is varied from low to high, it will be found that X_C decreases with an increase in frequency. If the frequency remains constant and capacitance is increased, X_C will decrease.

(1) The unit of measure of capacitance is the farad (f). Values of capacitance are usually given in terms of microfarads (uf) and picofarads (pf).

(a) 1 microfarad = 1/1,000,000 farad = 0.000,001 farad = 1×10^{-6} farads.

(b) 1 picofarad = 1/1,000,000,000,000 farad = 0.000,000,000,001 farad = 1 x 10^{-12} farads.

(2) One more fact about capacitors: they should never be used in circuits that place a voltage across the capacitors which exceeds the maximum safe rated value of voltage. To do so may destroy the dielectric and cause a breakdown of the circuit.

16. OPERATION OF CIRCUIT ELEMENTS

a. A knowledge of the individual properties and characteristics of the three circuit elements, resistance, inductance, and capacitance, is necessary to understand how these circuit elements operate in an actual circuit. Figure 24 shows a circuit containing all three circuit elements, so arranged that if switch S1 is closed, dc will be applied to the circuit, and if switch S2 is closed, ac will be applied to the circuit. The ground symbol shown on the diagram indicates that all points in the circuit so marked with this symbol are connected to a metal chassis, or base, on which the circuit is constructed; thus, all points bearing the ground symbol are actually connected together (via the metal in the chassis). This chassis ground symbol is used quite frequently in circuit diagrams to indicate that a part or a circuit element is connected to the chassis. The symbol does not necessarily mean that the part is actually connected to an earth ground, although it is sometimes used in this way in transmitter and receiver circuits.

b. Examination of the circuit in figure 24 shows that there are three possible paths through which current may flow. The first is through resistor R1 and back through ground (or the chassis) to whichever power source is in use; the second is through capacitor C and resistor R2 and back through ground; the third is through inductor L and resistor R3 and back through ground. Note that all three paths are connected in parallel. The path through the dc voltmeter (V) passes a negligible amount of current and therefore is not considered to be a current path.

c. The first step in the study of this circuit is to turn switch S1 on. Direct current will flow through resistor R1, the first path; the amount of current which flows through this path will depend on its resistance. Practically no current will flow in the second path since the dielectric of capacitor C acts as an insulator, and thus the capacitor will not pass dc. Although no current is flowing in the second path, voltmeter V, which is connected across all three paths in parallel, indicates that there is a voltage present across R2 and C. Also, if the dc voltmeter (V) were placed across C, the same value of voltage would be found across it, since there is no current flowing in this path and, consequently, there is no voltage drop across R2. This example shows that it is possible for a voltage to be present in a circuit, even though the circuit is open (that is, there is no flow of current). Current will flow in the third path, since the only opposition of current flow in this branch of the circuit is the dc resistance of the coil windings of inductor L and the resistance of resistor R3. The amount of current flow will be determined by the total resistance in this path; that is, the sum of the dc resistance of L and the resistance of R3.

d. The second step in the study of this circuit is to turn switch S1 off and turn switch S2 on. Low-frequency ac is now applied to the circuit. When

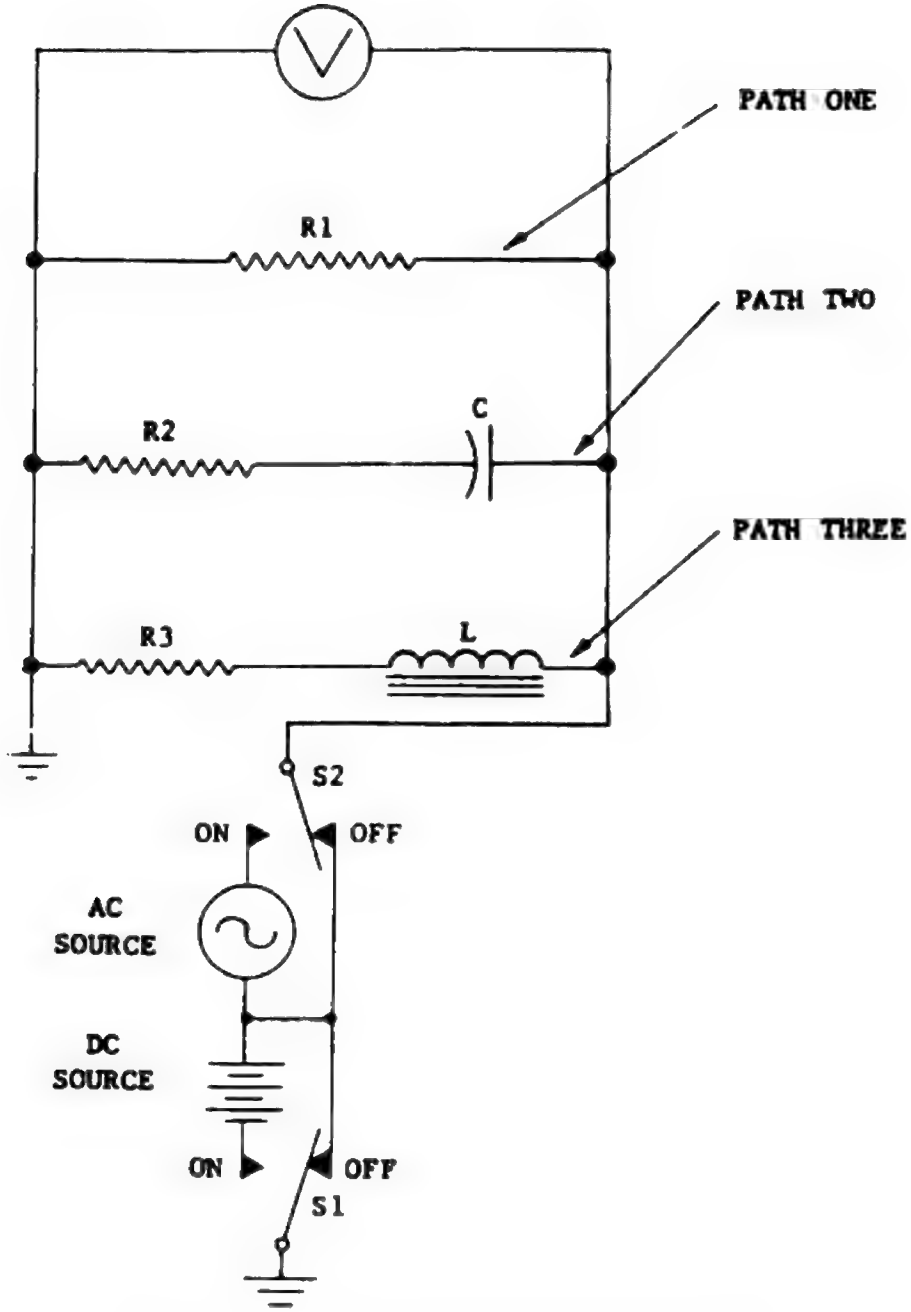


Figure 24. Operation of circuit elements.

this is done, current will flow through resistor R1 in the first path. Since a resistor offers the same opposition to ac as to dc, the current flowing in this path will be the same regardless of whether ac or dc is applied to the circuit. In the second path, the impedance will be high, due principally to the very high reactance of the capacitor. Very little current will flow in this path, so most of the applied voltage will appear across the capacitor, and a small voltage across the resistor. The impedance of the third path will be low because of the low reactance of the coil at low frequencies. The current in this branch will, therefore, be quite large. The voltage across the resistor will be large because of the high current, and the voltage across the coil will be small because of the small reactance.

e. The third step in the study of this circuit is to change the frequency of the ac generator to a high frequency while maintaining the same voltage amplitude. The current through resistor R1 will remain unchanged, but the currents in the inductive and capacitive branches will be just the opposite of what they were in the low-frequency condition. The capacitive path will now have a low impedance because of the low reactance of the capacitor at high frequencies. The current through resistor R2 will be high, causing a high-voltage drop across it. The voltage across capacitor C will be low due to its low reactance. The impedance of the third path will be high because of the high reactance of the coil at high frequencies. Very little current will flow in this branch, therefore, causing a low voltage across resistor R3. A high voltage will appear across the coil because of its high reactance.

f. The effect of both ac and dc on the circuit components can be determined by turning switches S1 and S2 on at the same time. The important effects will be those caused by changing from low frequency to high frequency. The path through R1 will carry both dc and ac current equally, regardless of the frequency used. The path through R2 will carry a small ac current at low frequencies and a large ac current at high frequencies. Direct current will be blocked from this branch because of the insulating property of a capacitor. (When used in this manner, the capacitor is often called a blocking capacitor.) Notice that the dc current through R3 remains the same, but the ac current will change inversely to the change in frequency. High-frequency current will be greatly reduced, or choked by the coil's action in the branch containing R3. For this reason, a coil in series with a dc circuit containing ac is often called a choke coil. Thus it can be seen that with both ac and dc present in a circuit, the current flow of either may be permitted, stopped, or restricted by the proper choice of circuit component values.

17. IMPEDANCE

The total opposition to the flow of ac is called impedance, and is designated by the letter Z. Impedance is the opposition to current flow caused by both the resistance and the reactance in an ac circuit, and it is measured in ohms. Resistance and reactance cannot be added together by simple addition to give the impedance because there is a 90° angular difference between them at all times. The resistance in the circuit absorbs electrical energy and converts it to heat, whereas reactance stores electric energy temporarily in the form of a magnetic or an electric field, and returns it later to the circuit whence the energy came.

a. Significance of Impedance. Since the value of impedance will always be greater than either the resistance or reactance taken as a separate value, the total current flowing in the circuit will be limited by the value of impedance, not by resistance or reactance alone. Since the impedance is an overall circuit characteristic, equipment manufacturers usually quote characteristics of their equipment in terms of their input and output impedances.

b. Impedance Matching. Maximum power is transferred to a load only when the impedance of the load equals that of the source. Regardless of the method used to achieve impedance matching, the purpose is the same, namely, to alter the impedance characteristics of the circuit or its load, or both, so that each matches the characteristics of the other.

18. RESONANCE

a. As stated previously, inductive reactance increases with an increase of frequency, whereas capacitive reactance decreases with an increase of frequency. At some frequency, then, they are equal and the net reactance (difference between the two) is zero ($X_L - X_C = 0$). The frequency at which this occurs is called the resonant frequency.

b. Any circuit containing a combination of inductance and capacitance is resonant to some particular frequency. By making one or both variable, it is possible to resonate or "tune" the circuit to any desired frequency within the limits of their variation.

c. The condition of resonance depends on three factors: inductance, capacitance, and frequency. Resonance can be obtained by varying any one of these three factors while the other two are held constant. And for a given set of inductance and capacitance values, there will be only one frequency at which the circuit will be resonant.

d. All tuned circuits possess some resistance; usually resistance is concentrated in the inductance and distributed throughout the wiring that connects the tuned-circuit components. This resistance causes the tuned circuits to react in particular fashions, as will be discussed in paragraphs 19 and 20.

e. When you tune in your favorite radio station on your home radio receiver, you are, in effect, changing the capacitance, so that the combination of this capacitance and inductance forms a tuned circuit that resonates to the frequency of the desired station. This tuned circuit, to be effective, must suppress all other signals that are picked up by the antenna. We are speaking here of only one tuned circuit, but in a practical radio receiver more than one is used since each tuned circuit will assist the other to do a better job.

(1) To receive a higher frequency station, the plates of the tuning capacitor are unmeshed, giving a smaller value of capacitance.

(2) To receive a lower frequency station, the plates of the capacitor are partially meshed, resulting in a larger value of capacitance.

(3) The tuned circuit could also be resonated by keeping the capacitance at a fixed value and varying the inductance. However, it is more feasible, mechanically, to vary the capacitance.

19. SERIES-TUNED CIRCUIT

The series-tuned circuit shown in A of figure 25 consists of a combination of resistance, inductance, capacitance, and a source of ac voltage connected in series.

a. At resonance the inductive and capacitive reactances cancel because they are equal and opposite to each other. The circulating current in the circuit is thus limited only by the resistance. The line current for a series-tuned circuit at resonance is therefore $I = E/R$ where E is the applied voltage and R is the total resistance of the circuit. If the total resistance of the circuit is small, the line current can be very large, relatively speaking, up to

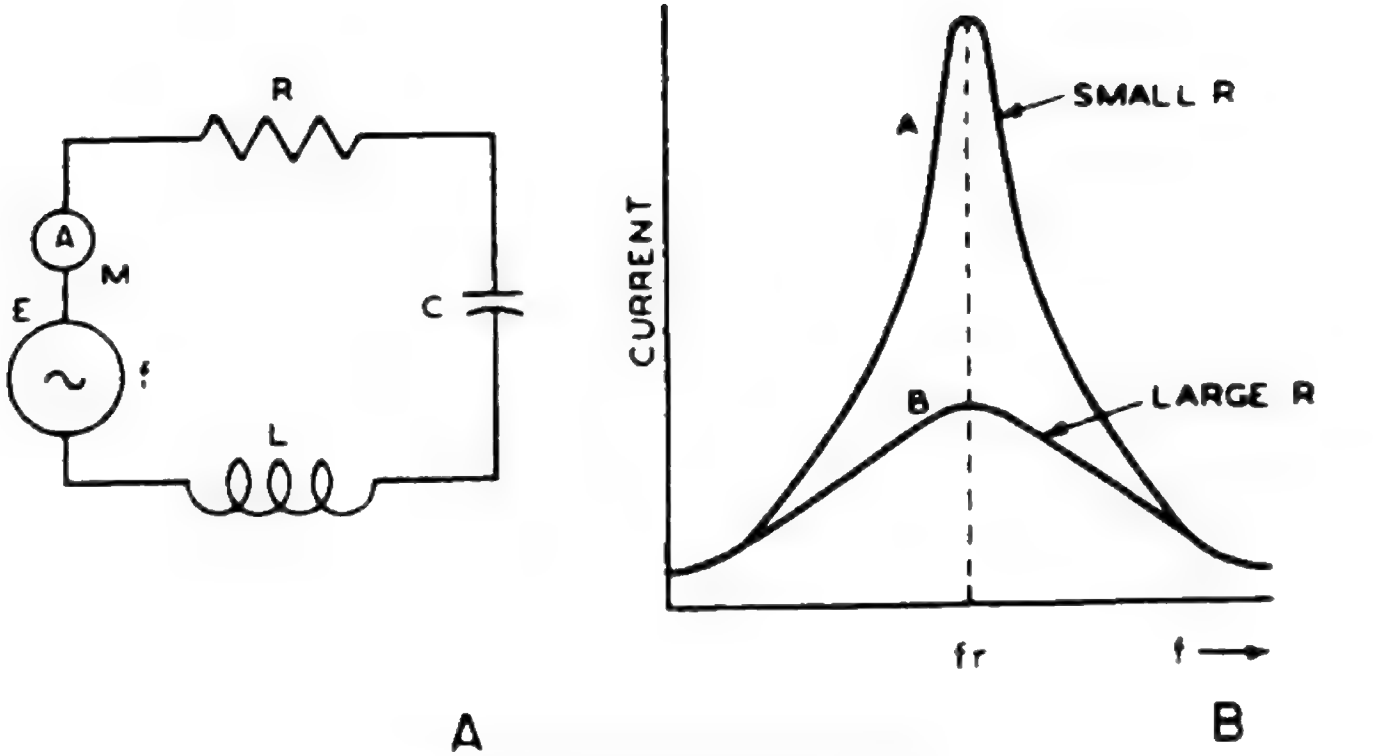


Figure 25. Series-tuned circuit.

the limit of the generator capability. The voltage between the ends of the series-tuned circuit at resonance is the smallest possible value which the circuit constants will permit, because the opposition to current flow from the generator is the smallest value at resonance. Thus we say the impedance of a series-resonant circuit is minimum at resonance.

b. The voltage drop across the inductor and the capacitor can be many times the applied voltage, because E = I x X. This increase in voltage is sometimes called the resonant rise of voltage, since the rise is greatest at resonance.

c. At frequencies below resonance, the capacitive reactance predominates and the circuit acts like a capacitor in series with a resistor. At frequencies above resonance, the inductive reactance predominates and the circuit behaves like an inductor in series with a resistor.

d. If the graph of line current is plotted against frequency, as in B of figure 25, the resultant curve is called a response curve. In a tuned circuit having a small resistance value, the current rises sharply near the resonant frequency (fr), whereas a large circuit resistance produces a curve that is relatively broad and flat. The circuit represented by curve A of the figure is said to be much more selective, or have more selectivity than that represented by curve B. This circuit can sharply discriminate against frequencies on either side of resonance. The height of the peak of the curve indicates the ability of the tuned circuit to produce an output voltage across either the inductance or capacitance. The circuit represented by curve A is said to be more sensitive, or have more sensitivity than that represented by curve B. Selectivity and sensitivity are two important characteristics of tuned-circuits.

20. PARALLEL-TUNED CIRCUIT

a. If a coil and a capacitor are connected in parallel with a variable-frequency source of ac, as in A of figure 26, the combination is called a parallel-tuned, or parallel-resonant, circuit.

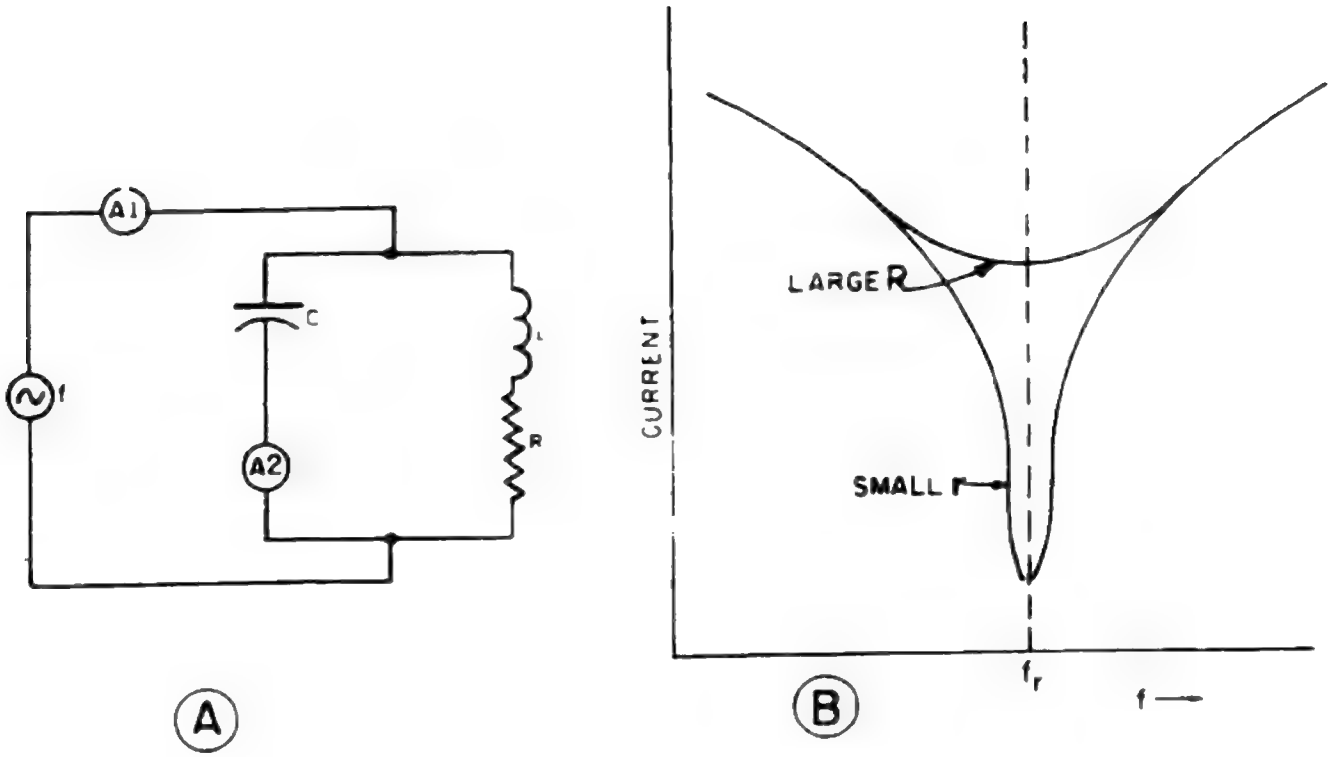


Figure 26. Parallel-tuned circuit.

b. In a parallel-tuned circuit, R appears only in the L branch. This results when the L and C branches are placed in parallel across the generator E. Because of this fact, there are now two paths through which the current may flow: one path through L and one through C.

c. If the ac source is set at a low frequency, most of the current will flow through the coil, since the reactance of the coil will be small for low-frequency ac, and the reactance of the capacitor will be large. On the other hand, if the ac source is set at a high frequency, most of the current will flow through the capacitor, since its reactance will be small at high frequencies, while the reactance of the coil will be large.

d. At the resonant frequency (fr), the reactance of C is equal to that of L in most of the practical radio circuits. Since the inductive and capacitive reactances are equal and opposite, they cancel out, and the only limitation to current flow at resonance within the tuned circuit is the resistance. Because

the voltage across either L or C is equal to the large circulating current times reactance, the voltage developed can be very large. In fact, if R is low, the voltage developed across the tuned circuit may be equal to the applied voltage E. At this time, current drawn from the generator (line current) will drop to nearly zero. Thus we say that the impedance of a parallel-tuned circuit at resonance is maximum.

e. The line current flowing to the parallel-tuned circuit in A of Figure 26 can be measured by meter A1. If the source frequency is varied from a low frequency through the resonant frequency to a high frequency, the line current will rapidly decrease from its highest value at the low frequency to a minimum at the resonant frequency, and will then rise again to a high value at the high frequency. The current characteristic of this circuit is shown in B of Figure 26. This graph indicates that the circuit impedance is maximum at resonance, and decreases on either side of the resonant frequency.

f. Selectivity and sensitivity of a parallel-tuned circuit are determined to a large extent by the amount of resistance in the inductor. This characteristic is similar for both series-tuned and parallel-tuned circuits. The characteristics of a parallel-tuned circuit at resonance can be summed up as follows:

(1) Circulating current around the loop of L, C, and R is maximum.

(2) Line current from the generator is minimum.

(3) Impedance presented to the generator is maximum.

LESSON EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answer in the subcourse booklet.

1. Two of the particles that make up an atom carry electrical charges. These particles are

a. neutrons and protons.
b. protons and electrons.
c. protons and molecules.
d. electrons and neutrons.

2. All substances will pass electric current to some extent, but certain substances pass it more easily than others. Electrical current will flow more easily through copper than through glass because, compared with glass, copper has

a. higher resistance.
b. lower conductivity.
c. more free neutrons.
d. more free electrons.

3. Correct usage of electrical terms is important as a basis for understanding electrical fundamentals. The term electromotive force has the same meaning as the term

a. power.

b. voltage.

c. current.

d. resistance.

4. Assume that you are to measure and report the amount of resistance in an electrical circuit. The unit that you will use to report this measurement is the

a. ohm.

b. volt.

c. watt.

d. ampere.

5. Ohm's Law for dc circuits expresses a relationship among

a. inductance, capacitance, and frequency.

b. current, resistance, and capacitance.

c. resistance, frequency, and current.

d. current, voltage, and resistance.

6. Which statement accurately describes the action that takes place in the dc circuit shown in figure 27?

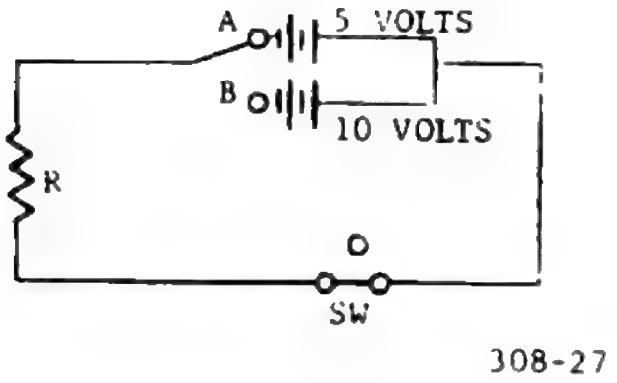


Figure 27. Series dc circuit.

a. Current decreases when battery B is inserted.

b. Current remains the same when battery B is inserted.

c. The voltage drop across R decreases when battery B is inserted.

d. Current ceases when switch SW is opened, and the applied voltage appears across the terminals of the switch.

7. Assume that a circuit has four equal resistors connected in parallel. Further assume that two resistors are removed from the circuit, one at a time. This action will result in a current

a. decrease and a voltage increase.

b. increase and a voltage decrease.

c. decrease and no change in voltage.

d. increase and no change in voltage.

8. One characteristic of a parallel-resistive circuit made up of resistors having different values is that the

a. current is different through each resistor.

b. current divides equally through each of the resistors.

c. voltage across each resistor depends on the size of the resistor.

d. voltage across each resistor is the value of the supply voltage divided by the number of resistors.

9. What is the value of voltage across resistor B in the series-parallel circuit shown in figure 8?

a. 2 volts

b. 5 volts

c. 7 volts

d. 10 volts

10. What is the power in a circuit if the current is 5 amperes and the total resistance is 150 ohms?

a. 6 watts

b. 167 watts

c. 750 watts

d. 3,750 watts

11. Magnetism is very important in electricity and electronics. It is the basis of operation for devices such as

a. generators, batteries, and motors.

b. transformers, motors, and batteries.

c. generators, transformers, and motors.

d. batteries, transformers, and generators.

12. The action that will NOT aid in making an electromagnet more powerful is

a. winding more turns on the coil.

b. increasing the amount of current flow.

c. reversing the direction of current flow.

d. substituting a different type of coil material.

13. The most practical means of increasing the output voltage of a generator is to increase the

a. field strength by passing more current through the field windings.

b. diameter of wire in the armature coil.

c. resistance of wire in the field coils.

d. number of field poles.

14. A loop or single turn of wire on the armature of an ac generator produces a continuously changing voltage during its rotation in the magnetic field. Maximum voltage is produced when the loop sides are

a. cutting a maximum number of flux lines.

b. moving parallel to the direction of the field.

c. standing still at a position of maximum magnetic flux.

d. standing still at a position of minimum magnetic flux.

15. The property that enables a coil to develop an opposing voltage is

a. counter EMF.

b. self-inductance.

c. transformer action.

d. inductive reactance.

16. The phase relationship of current and voltage when applied to an inductor is that the

a. applied voltage leads the current.

b. current leads the applied voltage.

c. current and applied voltage are in phase.

d. current and applied voltage are 180 degrees out of phase.

17. The circuit component that has the property of opposing a change of applied voltage is the

a. rheostat.
c. capacitor.
b. inductor.
d. potentiometer.

18. The amount of ac flowing in a capacitive circuit can be measured with an ac ammeter. Yet, the dielectric in a capacitor insulates against current flow. The apparent current flow read by the ammeter is due to

a. development of a counter EMF.

b. current leaking through the dielectric.

c. changing polarity across the capacitor.

d. ability of the capacitor to oppose any change in current.

19. In a circuit containing resistor, inductors, and capacitors the total opposition to ac is termed

a. capacitive reactance.
c. resistance.
b. inductive reactance.
d. impedance.

20. The impedance of a circuit can be represented by the hypotenuse of a right triangle where the other two sides represent reactance and resistance. The significance of this representation is to show that in any circuit the impedance is greater than

a. reactance hut smaller than resistance.

b. resistance but smaller than reactance.

c. the sum of resistance and reactance.

d. either resistance or reactance.

21. Resonance may be achieved in an LC circuit by changing any one of three factors. The factor that will NOT affect resonance is

a. frequency.
c. inductance.
b. resistance.
d. capacitance.

22. Assume that you are adjusting the frequency of transmission of a radio transmitter by varying the capacitance of a tuned circuit. If you need to lower the frequency of transmission, you change the position of the rotor plates with respect to the stator plates so as to

a. mesh the plates more fully, thus increasing capacitance and reducing the capacitive reactance.

b. mesh the plates more fully, thus decreasing capacitance and increasing the capacitive reactance.

c. unmesh the plates, thus decreasing capacitance and increasing the capacitive reactance.

d. unmesh the plates, thus increasing capacitance and decreasing the capacitive reactance.

23. Which statement accurately describes the effect of resonance in a series-tuned circuit?

a. If the total resistance of the circuit is small, the line current is also small.

b. At resonance, the circuit acts like an inductor in series with a resistor.

c. At resonance, the circuit acts like a capacitor in series with a resistor.

d. The circulating current in the circuit is limited only by the resistance.

24. The characteristics of a parallel-tuned circuit when tuned to resonance are

a. minimum circulating current and minimum impedance.

b. maximum circulating current and maximum impedance.

c. minimum circulating current and maximum impedance.

d. maximum circulating current and minimum impedance.

25. In the four statements below, comparisons are made between characteristics of series-tuned and parallel-tuned circuits at resonance. Which statement is correct?

a. Circulating current of a series-tuned circuit is maximum, while the circulating current of a parallel-tuned circuit is minimum.

b. Line current of a series-tuned circuit is maximum, while the line current of a parallel-tuned circuit is minimum.

c. Impedance presented to the source by either a series-tuned or parallel-tuned circuit is minimum.

d. The voltage developed across either a series-tuned or parallel-tuned circuit is maximum.

CHECK YOUR ANSWERS AGAINST LESSON 1 SOLUTION SHEET PAGES 42 & 43 AND MAKE NECESSARY CORRECTIONS.

HOLD ALL TEXTS AND MATERIALS FOR USE WITH EXAMINATION.

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SUBCOURSE 308.....Introduction to Electricity

All references are to the Attached Memorandum.

1. b--para 1b

2. d--para 2a(2)

3. b--para 2b(2)

4. a--para 2c

5. d--para 3a

6. d--para 3b

7. c--para 3c, 5d(1), 5e(l)

In a parallel circuit the same voltage is applied across each element. As each resistance is removed from the circuit, total resistance increases. By Ohm's law, as resistance increases with voltage remaining constant, current decreases.

8. a-para 5e(2)

9. b--para 6b

Since resistor B in parallel with series resistors V and W yield a parallel resistance of 5 ohms, the 10-volt source voltage will be divided equally between resistors A and B.

10. d--para 7b

$P = I^2R = 5^2 \times 150$

$P = 25 \times 150 = 3{,}750$ watts

11. c-para 9

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12. c--para 10b(1), (2), (3)

13. a--para 11d

14. a--para 12b(2), (4)

15. b--para 14a(11)

16. a--para 14b(5)

17. c--para 15

18. c--para 15a(2), (3)

19. d--para 17

20. d--para 17a

21. b--para 18c

22. a--para 18e(2)

23. d--para 19a

24. b--para 20f(1), (3)

25. b--para 19a, 20d